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Developing and Mapping Rainfall Intensity, Duration, and Frequency Curves in Al-Faria Catchment

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Abstract

The rain intensity relationship is one of the most used tools in water resource engineering, mainly to determine precipitation intensity in the return period and period. In light of this, this study aims to develop the IDF relationship to precipitation for the Alvaria catchment. The height of the ground surface in the catchment varies greatly. With mild winters in the rain and mild hot summers, the climate in the Al Faria catchments is Mediterranean and semi-arid. Al Faraa watersheds are measured by six precipitation stations. These stations are Nablus, Taloza, Tamoon, Tubas, Beit Dajan and Al-Faraya with around 48 years of data. The maximum values of the annual precipitation data were analyzed.

The results demonstrated that the Gumbel distribution is appropriate for the data and can be used for future estimates. After assessing and completing all available data, the IDF curves for stations were developed, and watershed maps from these curves were developed using Reverse Distance Weight (IDW) as a interpolation tool through ArcGIS. These maps can be used to find precipitation intensity which can also be found directly (without using curves or maps) using the software created by Matlab. ArcGIS provides an IDF map for a specific period and duration while using Matlab, allowing the IDF curve to be displayed for any point and any return period and duration.

Keywords: Mapping, Rainfall Intensity, Duration, Frequency Curves, return period

الملخص

تعتبر علاقة شدة المطر واحدة من أكثر الأدوات استخدامًا في هندسة موارد المياه ، وذلك بشكل أساسي لتحديد كثافة هطول الأمطار في فترة وفترة العودة. في ضوء ذلك ، تهدف هذه الدراسة إلى تطوير علاقة جيش الدفاع الإسرائيلي بهطول الأمطار في مستجمع ألفاريا. يختلف ارتفاع سطح الأرض في مستجمعات المياه اختلافًا كبيرًا. مع فصول الشتاء المعتدلة في المطر وصيف حار معتدل ، يكون المناخ في مستجمعات مياه الفارعة متوسطيًا وشبه جاف. تقاس مستجمعات مياه الفرعة بست محطات هطول. هذه المحطات هي نابلس ، طلوزة ، طمون ، طوباس ، بيت دجن والفرايا مع حوالي 48 عامًا من البيانات. تم تحليل القيم القصوى لبيانات هطول الأمطار السنوية. أظهرت النتائج أن توزيع Gumbel مناسب للبيانات ويمكن استخدامه للتقديرات المستقبلية. بعد تقييم واستكمال جميع البيانات المتاحة ، تم تطوير منحنيات IDF للمحطات ، وتم تطوير خرائط مستجمعات المياه من هذه المنحنيات باستخدام عكس وزن المسافة (IDW) كأداة استيفاء من خلال ArcGIS.

يمكن استخدام هذه الخرائط للعثور على كثافة هطول الأمطار والتي يمكن أيضًا العثور عليها مباشرة (بدون استخدام المنحنيات أو الخرائط) باستخدام البرنامج الذي أنشأته Matlab. يوفر ArcGIS خريطة IDF لفترة ومدة محددة أثناء استخدام Matlab ، مما يسمح بعرض منحنى IDF لأي نقطة وأي فترة عودة ومدة

الكلمات المفتاحية: رسم الخرائط، كثافة هطول الأمطار، المدة، منحنيات التردد، فترة العودة

Introduction

Statistics and evaluation the data of extreme rainfall are essential in planning and management of water resources for design purposes in construction of sewer and storm systems and determination of the mandatory discharge capacity of canals. So they are important to prevent flooding, thus reducing the loss of lives Insurance of water damage(Ballabio et al., 2017; Riahi, Hatira, Baccouche, & Nakouri, 2018), and evaluation of risky meteorological conditions(Gong, Zhang, & Wang, 2018). Studies on the rainfall intensity–duration– frequency relationship have received plenty of attention in the past few decades .(Tiwari & Agarwal, 2017; Vasu, Lee, Lee, Park, & Chae, 2018)

Rainfall intensity–duration–frequency (IDF) curves represent the main source of data used by engineers to predict rainfall intensity. IDF curves are a probabilistic tool useful in planning and design studies, those curves enable assessment of the extreme characteristics of rainfall and provide a simple means of communicating information about local extremes . Urban drainage design is often based on the values provided through IDF curves.

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Rainfall intensity–duration–frequency IDF curves are graphical representations of the amount of water that falls within a given period in catchment areas. IDF curves are used to aid the engineers while designing urban drainage works. The establishment of IDF relationships was done as early as 1932 by Bernard(Ballabio et al., 2017) . Since then, many sets of IDF relationships have been constructed for several parts of the globe. However, such relationships have not been accurately constructed in many developing countries(Vasu et al., 2018) .

Al-Faria catchment has a high spatial and temporal rainfall variability. Seven locations were involved in rainfall measurement: Nablus, Talluza, Tammun, Tubas, Beit Dajan, salim and Al-Faria stations. Rainfall gauges (daily data measurement) are available in six locations (Nablus, Talluza, Tammun, Tubas, Beit Dajan and Al-Faria). In addition, four tipping bucket (A type of recording rain gage; measures rainfall with a cycle of 0.2 millimeter) rain gages were installed in Talluza, Tubas, Tammun and Salim.(Nadler, 2019)

Methods

After the identification of the research problem, the first step in the research was to review the previously existing literature to develop ideas and draw a general picture of the whole situation(Ehmele & Kunz, 2019). After data of rainfall was collected,

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The next step was to assess the data and check its suitability and coverage for rainfall analysis followed by the creation of suggested rainfall stations because of the lack of coverage to the entire area of Al-Faria catchment(Nearing, Yin, Borrelli, & Polyakov, 2017). After that, an estimation of the missing data was established through the creation of relation between daily rainfall data (DRD) and fine resolution data (FRD) which is 10 minute, 20 minute, 30 minute, 1 hour, 2 hour, 4 hour, 6 hour, and 12-hour data (which were selected because they are the most commonly used) and by using equation of weighted filling missing data(Tiwari & Agarwal, 2017). After that, a significance analysis of DRD – FRD relations was done. Moreover, an analysis was made for the data to find the type of distribution it follows (which is mostly Gumbel distribution). After this, the IDF curves were developed for both available and suggested stations(Nearing et al., 2017; Sadeghiamirshahidi & Vitton, 2019). In order to reach the point where we can find the rainfall intensity of any point among Al- Faria catchment, spatial mapping and temporal development of IDF curves were carried out by both ArcGIS and Matlab.(Nearing et al., 2017)

Rainfall Stations

The optimal number of stations needed to measure rainfall data can be determined by using the following equations (Subramanya, 2013)

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$$N = \{ \frac{Cv}{Ep} \}^2 \quad \text{.. (1)}$$

Where

N: is the optimal number of stations

C_v: is the coefficient of variation of the rainfall from the existing stations in percentage

Ep: the allowable percentage of error in the estimation of mean aerial rainfall The coefficient of variation C_v was calculated by applying the steps below:

1. Calculate the mean of rainfall from the equation

$$P_{av} = \frac{1}{n} \sum P_i \quad \text{............. (2)}$$

2. Calculate the standard deviation

$$\sigma_{n-1} = \sqrt{\frac{1}{(n-1)} \sum (P_i - P_{av})^2} \quad \text{.................... (3)}$$

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3. Compute the coefficient of variation as

$$C_v = \frac{\sigma n{-}1 X\ 100}{P_a} \quad \text{.................................... (4)}$$

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The higher the percentage of error is, the fewer the number of stations there.

The previous statistical parameters were calculated using the data from the six stations, with:

P_{av} = 417.2 mm σ_{n-1} = 164.9 C_v = 39.5

Based on 11% error, the minimum required number of stations is 14. Existing stations (n) = 6
Additional stations required = (N-n) = 8

Results

Data Assessment (Annual Rainfall Estimation)

Moving on, from the result of **Section 4.1,** the current number of stations is not enough. Because of that, eight rainfall stations were suggested to properly cover the spatial distribution of rainfall over the catchment. Thus mapping of IDF curves will be much more accurate.

In Al-Faria catchment, the rainfall is affected by the variation in elevations. In general, when the elevation increases the rainfall increases. developed a spatial-oriented formula to find the rainfall based on the elevations, and geographic location, using multiple linear regression by using five stations (Nablus, Bet dajan, Talluza, Tubas and Tammun) as:

$$R = 8285 - 39.41X - 2.46Y - 0.34Z \quad (5)$$

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Where, R is the annual average rainfall in mm, X is the x-coordinate in km, Y is the y-coordinate in km and Z is the elevation in m.

After the equation was computed using five stations, the remaining station (Al-Faria) was used to verify the equation ($r^2 = 0.99$).

To complete the data required to make a good spatial distribution; the other eight stations became a must, we tried to distribute them in the most proper way over the empty region, the stations appear in **Figure 1**.

Figure 1: Existing and Suggested Rainfall Stations in Al-Faria Catchment

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*Salim is shown as triangle because it's daily data is invaluable.
For the eight suggested stations, annual rainfall was estimated using the developed formula 5

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Filling Missing Rainfall Data

Filling missing data was challenging at many levels, every station required a number of steps according to the type of data that was missing. Starting from Tubas, Tammun and Talluza stations, both daily rainfall data (DRD) and fine rainfall data (FRD) were available, but our FRD was limited to 5-10 years. We created a relationship between DRD and FRD, so our FRD was completed.

Talking about Salim which was missing long-term DRD, we started by using the equation 6 so we could use the equation result to create the DRD - FRD relation which was created before.

Moving to Nablus and Beit Dajan, we used the equation 6 to complete the missing FRD, and then we created the DRD - FRD relation.

The imaginary station that has no data required to create a whole new DRD and FRD using the equation 4.2 then rely on this data to create the final DRD
- FRD relation.

$$F_x = \left(\frac{P_{avx}}{n}\right) \sum_{i=1}^{n} \left(\frac{P_{y_i}}{P_{avi}}\right) \quad \text{.......... (6)}$$

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where:

P_x^y *is* the missing rainfall value at station x at time step y; (Sadeghiamirshahidi & Vitton)

P_{avx} is the long-term annual average of station x; (Sadeghiamirshahidi & Vitton)

P^y is rainfall value at station i at time step y; (Sadeghiamirshahidi & Vitton)

P_{avi} is the long-term annual average of station i.

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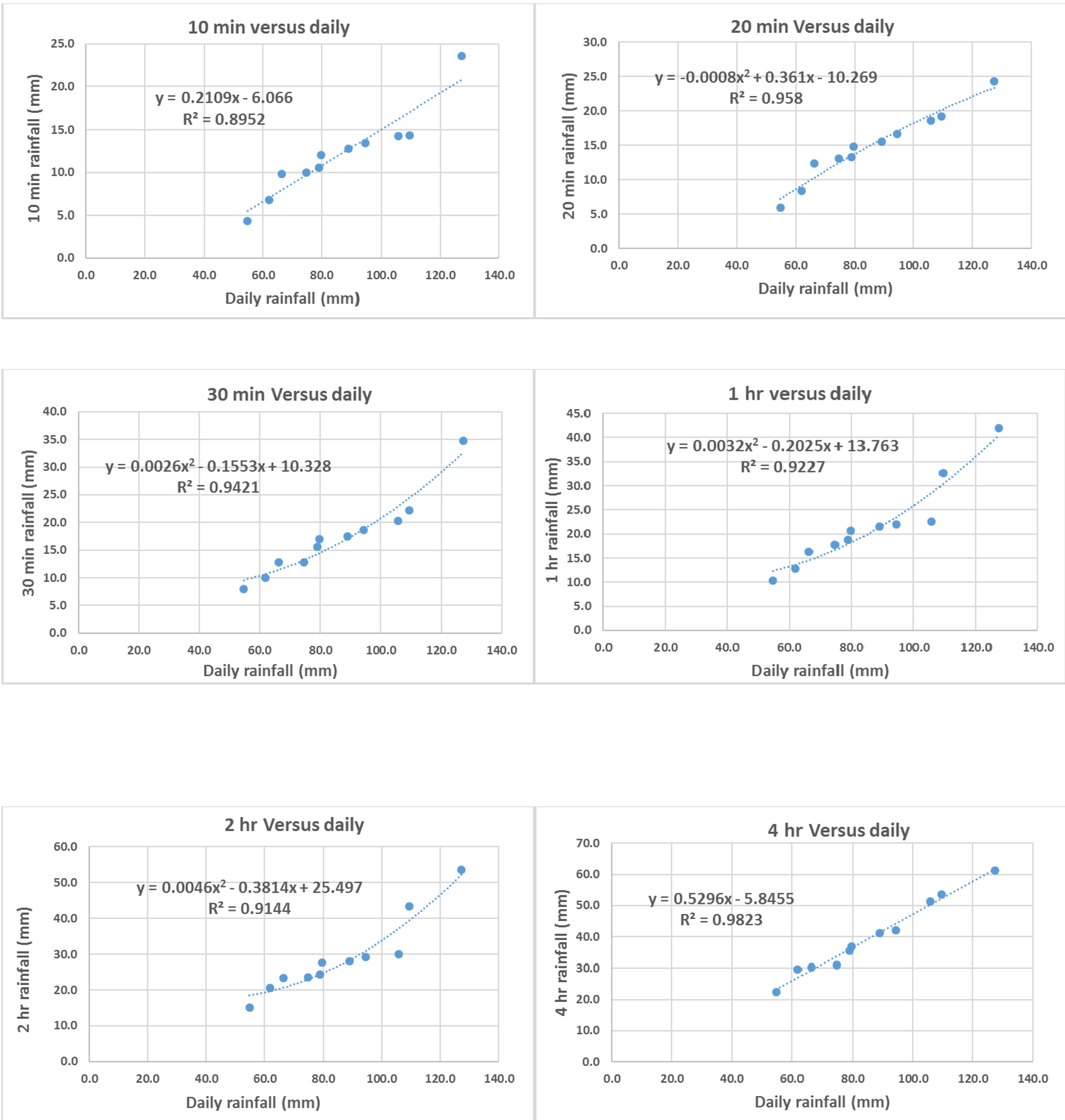
Figures 2 Shows the relations in Nablus station. Those relations were chosen as the best trend lines between FRD - DRD. Similar figures were developed for the rest of the stations.



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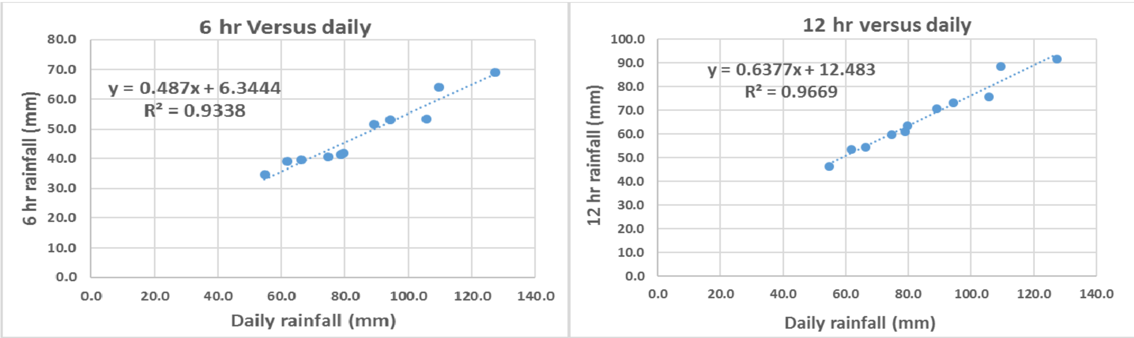

Figure 2 FRD versus DRD Relations

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Development of Rainfall Intensity-Duration-Frequency Curves

Table 1 summarizes the available data of the stations in Al-Faria catchment including the existing and suggested stations.

Table 1: Typical Characteristics of Rainfall Stations

NO.	**Station**	**X coordinate**	**Y coordinate**	**Record length (years)**	**Elevation (m)**	**Mean Annual (Sadeghiamirshahidi & Vitton)**
1	Nablus	178000	178000	42	570	637.9
2	Talluza	178006	186302	42	500	582.8
3	Tubas	184954	191685	33	375	386.8
4	Beit Dajan	185300	177800	40	520	377.9
5	Tammun	186500	187800	40	340	319.4
6	Al-Faria	196000	172000	47	-	198.

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					237	6
7	Salim	181174	179701	48	514	589.5
8	S8	181636	189910	48	247	577.4
9	S9	184058	185125	47	90	549.0
10	S10	188254	181698	47	-35	431.7
11	S11	193431	175454	48	-100	261.0
12	S12	196644	167399	47	-251	208.2
13	S13	193002	179575	46	-90	262.1
14	S14	198712	163558	47	-325	161.6

From rainfall measurements, for every year of record, determine the annual maximum rainfall depth over the specific durations. Common durations for design applications are:10-min, 20-min, 30-min, 1-hr,

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2-hr, 4hr, 6-hr, 12-hr, and 24-hr. then calculate rainfall intensity fir each rainfall depth.

The development of IDF curves requires that a frequency analysis be performed for each set of annual maxima, one each associated with each rain duration. The maxima data has been sorted and ranked. The basic objective of each frequency analysis is to determine the exceedance probability distribution function of rain intensity for each duration. The frequency analysis used to estimate the rainfall events is Gumbel distribution associated with given exceedance probabilities.

Mapping of IDF Curves Using ArcGIS

After the IDF curves of the fourteen stations were developed, the curves were used to mapping the spatial distribution of IDF curves over Al-Faria catchment.

The ArcGIS is a system for maps and geographic information, used to create maps, analyze mapped information and compile geographic data. The system was used to enter the rainfall data of the fourteen stations from both excel and the shapefiles of Al-Faria catchment. Then, interpolations were made using Inverse Distance Weight (IDW) interpolation method to find the IDF maps that give the rainfall intensity at any point within the catchment for a

given duration and return period. The equation of:

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$\sum^{n} (^{z i})$

—

i=1 d2 .... (7)

Z =________i

p $\sum n$ (^{1})

—

i=1 2 d

i

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Z_p is the rainfall intensity at the point p
(unknown point) Z_i is the rainfall intensity at
the point i (known point)
d_i is the distance between the interpolated point (unknown point) and the known point.

IDW method is the approved method in national weather service in United States. In addition, this tool is suitable for this research objective because it gives more influence for the stations when it is near the location needed, so the influence of the far station is minimum compared with the near one. From the available rainfall data, 54 IDF maps were developed for different duration and return periods as shown appendix 1 . These maps give available information for selected locations, which might help both decision makers, and resources planners to proper evaluate different hydraulic structures. For a particular return period for Al-Faria entire catchment. The maps were used to assign specific rainfall intensity magnitude to specific points via spatial interpolation along studied area.

The limitation of this method is the fact that the maps were developed for a specific durations (10, 20, 30 60, 120, 240, 360, 720, 1440 minutes) and
specific return periods (2, 5, 10, 20, 25, 50 years)

Therefore, if another duration needs to be determined between (10-1440 minutes) or return period between (2-50 years), another map must be developed by the same procedure. Furthermore, this method does not give IDF curves for a specific

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point. Because of that, a different way was applied to reach the objective by using the Matlab program.

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Mapping IDF Curves Using Matlab

To achieve the aim of the research, Matlab was used to write a program that allows inputting the (x,y) coordinates at any site in Al-Faria catchment for any return period between (2-50) years, and any duration between (10 -1440) minutes, then it computes rainfall intensity and presents the IDF curves in tabular and graphical forms..
(2-50) years and (10-1440) duration were chosen because they are the most commonly used for prediction of rainfall intensity.

All rainfall data available was used as a database for the program. A code of IDW method was written for interpolation techniques. To use this program, the (x,y) coordinates are needed to create IDF diagrams and IDF tables at a

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point. The program can determine the rainfall intensity at any return period for a given duration.

This program can be used as an alternative to the ArcGIS maps because when the user enters the (x,y) coordinates ,return period and duration, the program gives the rainfall intensity directly. **Table 2** show the comparison used to verify that the output of program matches the results of the maps.

Able 2 Matlab and ArcGIS Results

Duration (minutes) / Return period (year)	X	Y	Matlab	GIS
30/25	180105	185789	42.2	41.8
30/25	195015	175825	21.4	21.3
30/25	198471	166677	17.4	17.2
360/50	180173	182943	9.7	9.9
360/50	188984	183214	7.5	7.5
720/20	180106	177725	6.3	6.4

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Based on the above, it is fair to say that both ArcGIS and Matlab produce acceptable results. Although, using Matlab will allow displaying an IDF curve for any point and giving a rainfall intensity directly for any return period and duration, while ArcGIS gives an IDF map for a certain period and duration. This map shows the variation of rainfall intensity within the catchment.

Conclusions

Al-Faria catchment is located in the northeastern part of the West Bank, Palestine, with a total area of about 320 km^2. From about 900 m above mean sea level at Nablus Mountains, to about 350 m below mean sea level at the confluence with the Jordan River, the ground surface elevation in the catchment varies significantly. With mild rainy winters and moderately dry, hot summers, the climate in the Faria catchment is Mediterranean.

Al-Faria catchment is gauged by six rainfall stations; these stations are Nablus, Talluza, Tubas, Beit Dajan, Tammun and Al-Faria. The optimal number of stations was calculated based on statistical analysis. The minimum required number of stations is 14. The analysis of the extreme values of annual rainfall data was achieved. The results proved that Gumbel distribution fits the data and can be used for future estimations.

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After all data available was assessed and completed the IDF curves were developed for 14 stations, 54 maps for the catchment were made using these curves. These maps can be used to find intensity rainfall which also could be found directly using the program that was created using Matlab.

It is fair to say that both ArcGIS and Matlab produce acceptable results. While using Matlab will allow displaying an IDF curve for any point and giving a rainfall intensity directly for any return period and duration, ArcGIS gives an IDF map for a certain period and duration. This map shows the variation of rainfall intensity within the catchment.

Recommendations

Based on the on the results of this study and the struggles it gone through some points can be recommended for the future researches:

1. Install a recording rainfall gauges (e.g tipping buckets) in the catchment mainly in the lower part to get a real representation of spatial rainfall variation in the catchment.
2. Develop IDF curves for the West Bank similar the ones were developed for Al-Faria catchment.
3. Further development of the Matlab code given more real rainfall data

   in different catchments to be used for hydraulic engineering structures design.

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