Vegetated structure for urban outdoor comfort

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In Trujillo, Peru, where incident radiation on the horizontal surfaces can reach 2000 kWh/m^2 annually, the importance of shaded surfaces to provide high quality outdoor spaces is undeniable. The role of trees in urban environments is not only limited to landscaping, they contribute as well to urban quality and outdoor comfort in public spaces. However, Trujillo possesses only 2.1 m^2 of green area per habitant, 6.9 m^2 less than what the World Health Organization recommends. These facts suggest the need of trees in Trujillo to improve its urban quality.

Unfortunately, growing trees in urban environments is a challenge due to the immediate shock they suffer when transplanted into the city causing stunted growth and low resilience to stress factors such as pollution, harsh climate and vandalism.

The a34unm projects aims to equip public spaces with a temporary structure that emulates the benefits of a grown tree starting from the day it is installed, and at the same time protects a young tree in its core. When the tree is fully grown, and it naturally provides shade, the structure can be relocated to support another growing tree.

To shape the structure, the *Delonix Regia* tree species is chosen, due to its typical T shape and fast growing-rate. The waffle structural system allows space for modular shading panels, free airflow, and easy assembly and reproduction. Recycled wood formwork form concrete casting is used for the structure to reduce construction waste, and totora straw, a local organic material, for the shading panels. As radiation along the year is variable, the totora straw modular shading panels are operable, blocking solar radiation in summer and letting it in during the winter.

The a34unm project intends to be a mean of creating awareness of the benefits of a tree in an urban environment. Also, it is a social project that encourages citizens to actively participate in the growth of urban trees.

Keywords: outdoor thermal comfort, public space, urban vegetation, temporary structure

INTRODUCTION

Trujillo is located in the coastal north of Peru, at an altitude of 34 meters above sea level. It is the third most populous city and the second most populous metropolitan area of Peru. The climate is considered mild desert (BWh or BWn) according to the Köppen Climate Classification, and it has been known as the city of the everlasting spring because of its sunny and pleasant weather all year-round. The ambient temperature range between 14ºC and 30ºC due to the Humbolt Current, and the rainfall is low and sporadic. The radiation on the horizontal surface is high reaching the 2000 kWh/m2.annual. *(Figure 1.)*

Undoubtedly due to climate change, the weather on the region has been affected. According to the National Climate Change Strategy Report (2015), the minimum annual ambient temperature in the region will vary by 0.4ºC to 0.8ºC for 2030, but the registered ambient temperatures suggest a bigger variation from 26ºC on summer 2015 to 31ºC on summer 2017, leading to a perceived temperature of 30ºC and 34ºC respectively.

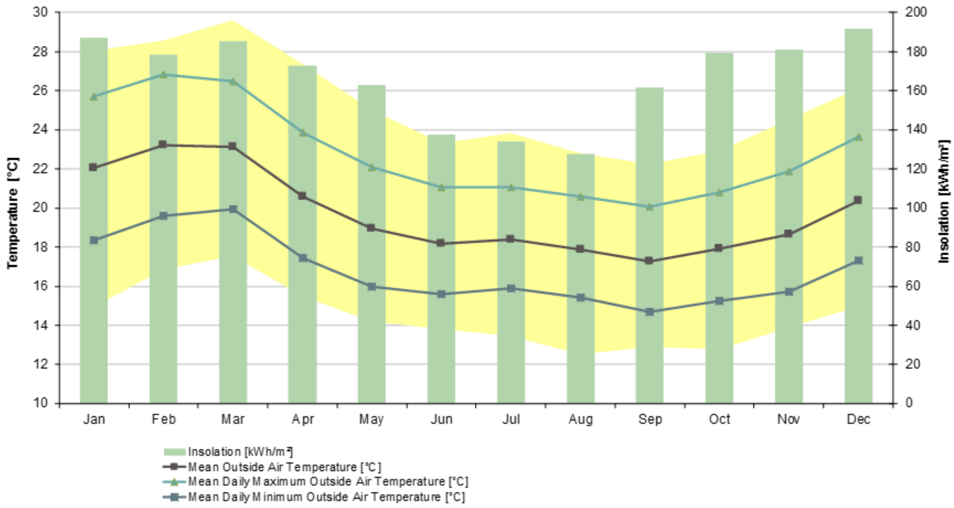


Figure 1. Ambient temperature and radiation
Source: Weather data post processing (Transsolar)

PUBLIC SPACE

Due to the increase of population moving in the city, and extreme conditions and aggravations as a result of climate change projection, there has been a slightly change on the urban temperatures at local scales. According to Brown, R *et al.* (2015) most cities are not designed to ameliorate these effects although it is well-known that this is possible, especially through evidence-based climate-responsive design of urban open spaces.

In cities like Trujillo, where the growth is fast, the public space is led to its own development, most of the times not meeting the user requirements or even the green area to solid surface ratio. Sometimes, to avoid green areas maintenance, public spaces are developed as large solid (concrete, tiles, paving stones, etc.) areas exposed to the high radiation, emphasizing the Urban Heat Island (UHI) effect. *(figure 2.)* Additionally, high radiation not only affects thermally the urban environment, but long-term exposure could generate melanomas and other types of skin neoplasms on people.

URBAN TREES

As previously described, in Trujillo large solid areas take over the city public space, leaving non, or reduced areas for vegetation. The World Health Organization recommends 9 m^2 of green area per habitant, but Trujillo only possesses 2.1 m^2 of green area/hab. To date, numerous articles have already discussed the capacity of urban vegetation (urban trees and “green areas”) to attenuate urban temperatures and combat UHI effects. As mentioned by Santos N. *et al.* (2018), the use of urban greenery is the most common technique that is used to mitigate UHI effects, reducing the surrounding urban ambient temperatures by 0.5ºC to 4ºC.

It is then seen a promising solution to ambient temperature reduction to increase vegetation on the urban areas. But reality shows that young transplanted trees can hardly make it to an adult live in the city. This is caused by various factors such as the immediate change from a controlled environment (nursery garden) to a harsh urban environment where they experience biotic and abiotic stress, from pollution, overheat, sudden soil adaptation and vandalism. *(Figure 2.)*

Figure 2. Young tree on the Main Square
Source: Google Street View

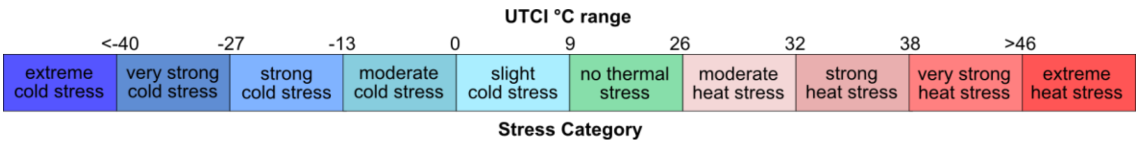
OBJECTIVE

The project objective is to equip non-vegetated public spaces in Trujillo with a temporary structure that emulates the benefits of a grown urban tree from the day it is installed, but at the same time this should provide protection for a young tree. According to this assumption, when a tree is fully grown it will naturally provide shade in the public space and the structure will be ready to be dissembled and relocated to support another growing tree.

METHODOLOGY

1st phase: numerical studies

- **Meteonorm** to obtain weather data from the local airport, in .109 format.
- **Microsoft Excel** to post process the weather data for the weather analysis.
- **Iowa Environmental Mesonet (IEM)** for wind direction and velocity, since errors with the wind data extracted from the weather file were found.
- **OpenFoam** for computational fluid dynamics that helped have a better understanding on wind flow and velocity in of the urban environment.
- **Rhinoceros + Grasshopper + Ladybug** plug-in for radiation study over the main square including shaded areas by trees.
- **TRNSYS 18** for outdoor thermal simulation related to material, wind velocity, shade and weather inputs.
- **Universal Thermal Climate Index (UTCI)** is a thermal comfort indicator based on human heat balance models and designed to be applicable in all seasons and climates and for all spatial and temporal scales.



2nd phase: design

- **Rhinoceros 5.0** for structure concept modeling, selecting the best shape according to the data found on the numerical studies and design knowledge.
- **Grasshopper** plug-in for concept shape parametrization, allowing the structure to be formed by modular pieces.

ANALYSIS

A weather analysis was made to identify the climate challenges/opportunities in Trujillo, obtaining the following results:

- Ambient temperature fluctuates between 12.5ºC and 29.6ºC, being 19.7ºC the yearly mean temperature. At a first glance, ambient temperature by itself does not represent a challenge for the structure design but, as mentioned before, the UTCI scale is being considerate to determine outdoor thermal comfort.

- Trujillo has a very strong value (2000 kWh/m2) in the horizontal radiation, which is considered as a thermal challenge in large-surface exposed areas, but a potential for energy harvesting purposes. The horizontal surface is considered as predominant due to Trujillo's location close to the equator and the little difference on the sun angle along the year. *(Figure 3.)*

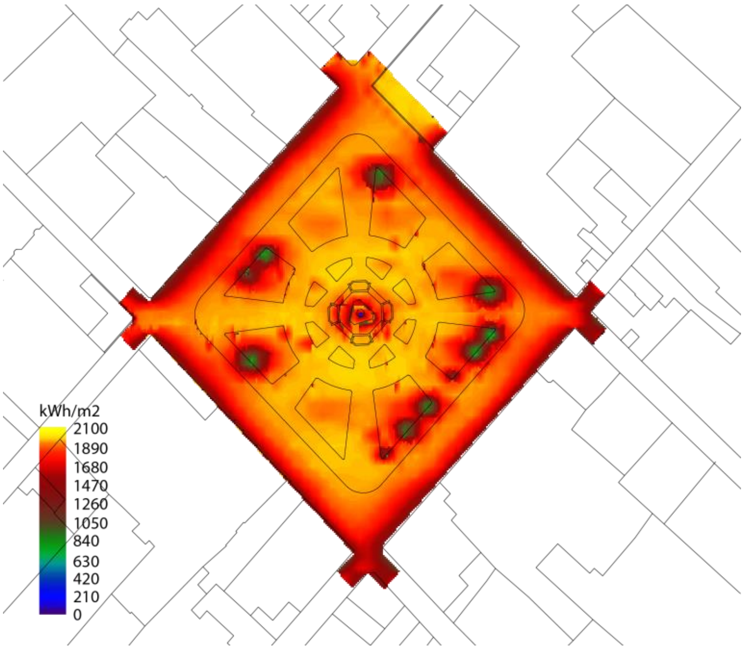


Figure 3. Radiation over Trujillo's main square concrete surface

- Humidity is above 12 g/kg about 66% of the year, which suggests dehumidification methods for the summer to decrease the discomfort.

- Wind speeds at the source (Martinez de Pinillos Airport Weather Station) average 3.8 m/s, but the results from the computational fluid dynamics study show a considerate reduction to 0.5 m/s in the urban area because of the city street configuration and obstacles. The low wind speed lead to still air areas, not allowing air renewal. *(Figure 4.)*

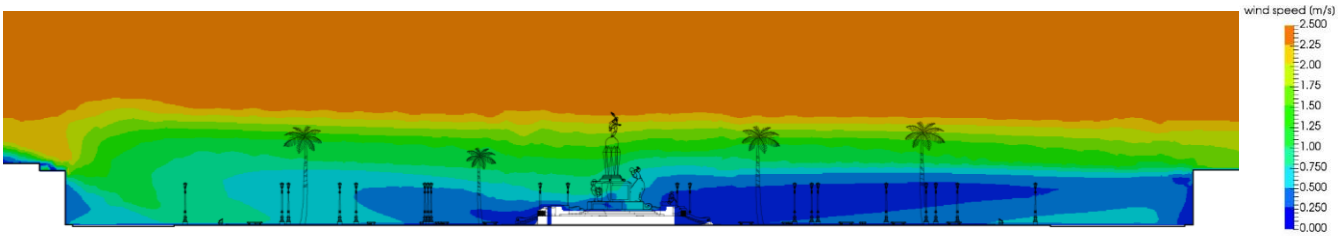
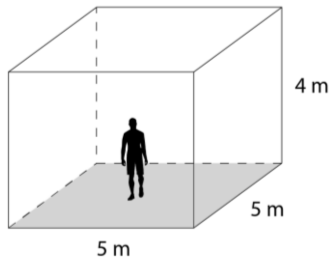


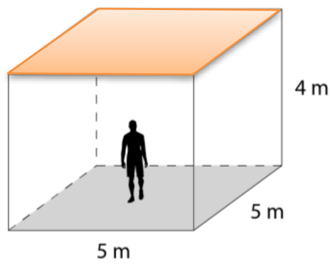
Figure 4. Computational Fluid Dynamics section study over Trujillo's main square

For the thermal simulation in TRNSYS the following boundary conditions were set:



VARIANT 1

- Box volume: 100 m^3
- Wind speed: 0.5 m/s
- Floor material: Concrete
- Condition: Unshaded



VARIANT 2

- Box volume: 100 m^3
- Wind speed: 0.5 m/s
- Floor material: Concrete
- Condition: Shaded

Two extreme dates where taken as reference for the results, the hottest day (march 17th) and coldest day (august 4th) of the year.

RESULTS

For both, the hottest day and coldest day, a shaded condition decreases the UTCI by a maximum of 5ºC between 10:00 and 16:00.
In the hottest day case, the highest UTCI value is 39.11ºC in an unshaded situation at 15:00, getting to 35.33ºC when a shading element is added.
In the coldest day case, the highest UTCI value is 30.55ºC in an unshaded situation at 13:00, getting to 24.97ºC when a shading element is added.

The UTCI scale sets that between 9ºC and 26ºC a person does not experience thermal stress and assumes these are excellent outdoor comfort condition. But according to experience in Trujillo, this is not the case. Locals being used to a very constant ambient temperature (12.5ºC to 29.6ºC) al year round and without exposure to harsh winter conditions, suggest adjustments on the UTCI scale to provide a more accurate to climate scale. *(Figure 5 and 6.)*

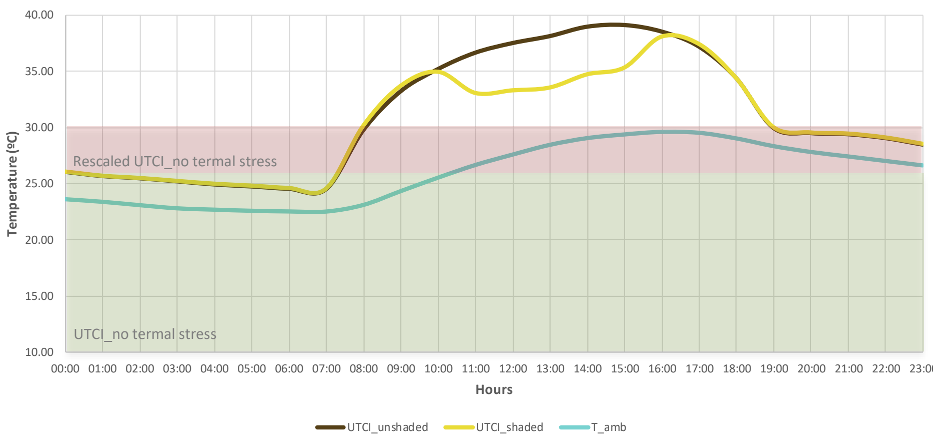


Figure 5. Hottest day results

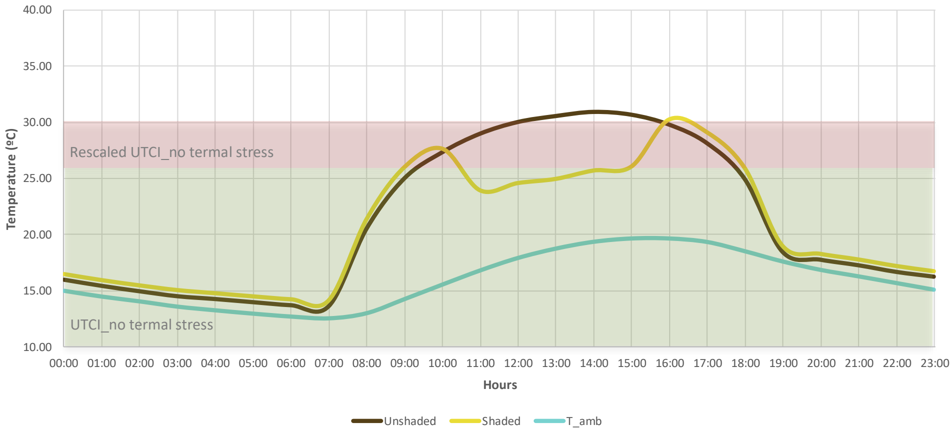


Figure 6. Coldest day results

After rescaling the UTCI to a range between 9ºC to 30ºC, the hottest day results still need to be reduced to meet the new range, while the coldest day results meet the "no thermal stress" range in the adjusted scale.
These new scale show a more expected result, where shade is needed in summer (high radiation days) and full radiation is needed in winter (low radiation days).

PROPOSAL

Conferring to the simulation results, the structure must be dynamic to provide outdoor thermal comfort on summer and winter to people and a relatively controlled environment for a young tree *(Figure 7 and 8.)*. Besides providing shade, the structure must be permeable, visually attractive, affordable and easy to reassemble in different parts of the city when needed, an address the requirements listed on the following table. (*Table 1.)*

PEOPLE	TREES	SOLUTION
Radiation exposure (winter)	Direct solar radiation all year round	· Vortex geometry · Waffle structure to provide shade at different angles
Radiation protection (summer)		· Operable flaps to gain solar radiation
Visual connection with trees	· Structure · Wind permeable · Protection from humans	· Waffle structure that lets the wind go through · Vegetated core
Affordable	-	· Local totora straw for operable flaps · Concrete formwork from construction sites
Easy to build	-	· Totora straw mats are commonly used for shade · Wood does not require qualified manpower
Easy to reassemble	-	· Parametric waffle structure with modular ribs

Table 1. Design requirements

Figure 7. High radiation days case

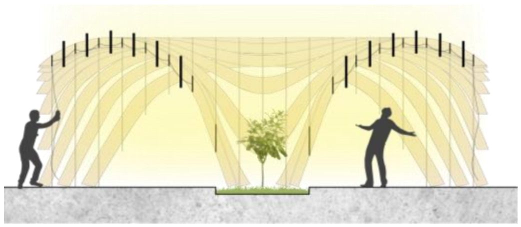


Figure 8. Low radiation days case

CONCLUSION

Two base cases were run in TRNSYS for this project, which lead to a first result that did not meet the actual thermal feeling of the outdoor space. According to the results, shading on public space is not enough, but experience prove the contrary. This suggested that the UTCI scale used as reference has a limited threshold that needs further studies on different climate conditions. Furthermore, measurements on site should be performed to accurately analyze the data and develop a UTCI scale.

For the worst case scenario some decrease on the UTCI was still need. Considering that the structure was developed as a passive urban strategy to improve outdoor comfort and increase the amount of urban trees, no additional mechanical systems where considered on the calculation, but for further adaptation photovoltaic panels can be considered to harvest energy since it is a site potential, providing energy for radiation activated operable system for the flaps, wind blow systems or dry mist systems.

The a34unm project intends to run as a social initiative for urban areas, thereby the success of the structure and spreading system should be tested.

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