Transsolar Academy
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Axolotl: A new Water Responsive Design Tool

Mexico City Master Planning Case Study

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Axolotl is an open source and user-friendly Rhinoceros – Grasshopper tool for water responsive design that allows architects and urban designers to include rain, green infrastructure (GI) and low impact development (LID) strategies in projects master planning. Based on daily precipitation data recorded from trustworthy meteorological stations, Axolotl uses this historical information and calculates surface runoff rates and volumes applying the Rational Method. Its components are developed in *Python*, which is a high-level programming language that enables the user to follow-up and test the tools for any possible improvement and/or any change required to facilitate their calculations. These are used to calculate different soil infiltration ratios, rain runoff depending on project surface types, buildings water demand, rainwater tanks sizing for water reuse and since it could be linked to TRNLizard components it's useful also for outdoor comfort UTCI calculations depending on the availability of rainwater storage in exterior areas. A Mexico City master planning design is shown as case study to demonstrate different rain management strategies application. The location has been selected due to the current challenges of Mexico City, which started in 2016 the program *"Towards a Water Sensitive Mexico City, public space as a rain management strategy"*, as an initiative to improve water resiliency urban design. Designed for, but not limited to, mexican cities, Axolotl is able to access information of more than 600 meteorological stations distributed in Mexico City, Nuevo León, Jalisco and Baja California.

Introduction

More than 25 % of homes in Mexico have irregular access to public potable water services and 6 % don't have connection to any clean water network system (Durán, 2018). Figure 1 shows how access to potable water is also related to geographical conditions, while in the south part of Mexico the people have access to 67 % of the total potable water, in the north its only 33 % (CONAGUA, 2017).

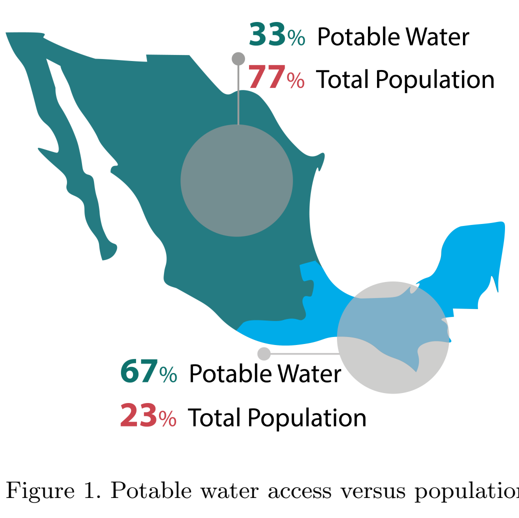

Figure 1. Potable water access versus population

Additionally, demographic growth and population explosion of urban centres increase the water demand for peoples daily activities, hence developers and designers challenges related to water management must be considered as part of projects master planning foundations. According to Mexico City Government(MCG), 35 % of water is lost due to leakage problems in the existing network (MCG, 2016), therefore maintenance plays a key role to maintain water access for all the population.

Figure 2. Water Square in Rotterdam (DeUrbanisten, 2018)

Potable water scarcity is not the only struggle for urban developers related to water management, there's also an increased potential of flooding as more and more natural land is covered by impervious surfaces such as pavement, concrete, glazing, etc. In response to this situation, water sensitive programs have emerged as a cutting-edge and innovative strategy to tackle down this problem using urban public spaces as water responsive structures that work together and help to delay, retain, store, reuse or drain the water, depending on the zone fundamental needs (MCG, 2016).

Axolotl has been designed as an additional effort to contribute in the design of new water responsive strategies, developed as a quantitative toolkit to foster the transition to water resilient cities.

Axolotl is a new tool that encourage this transition, helping architects in the early stages of design to consider water as a potential target for improvement in urban development, conceiving and testing ideas that might would end up having a positive environmental impact.

Vision

Axolotl main purpose is to help in the development of rainwater concepts, being assisted by specialized commercial software and meteorological data from approved stations. These two elements are essential in the process of design of water responsive strategies; available trustworthy precipitation data must be available for the site in study to produce reliable results.

The idea behind Axolotl is to provide designers the opportunity to develop water responsive designs and water balance calculations for projects master planning in an easy and user-friendly environment. Rhinoceros and Grasshopper provide this interface that combines master plan massing and their physical interpretation for climate responsive design.

Currently there are just few available tools that include parametric water analysis simulations; architects are most of the times unaware in the early design stage about the problems related to water management such as increased runoff and discharge rates (Chen, 2016).

Figures 3a and 3b show a schematic comparison for both conventional and water responsive design approaches.

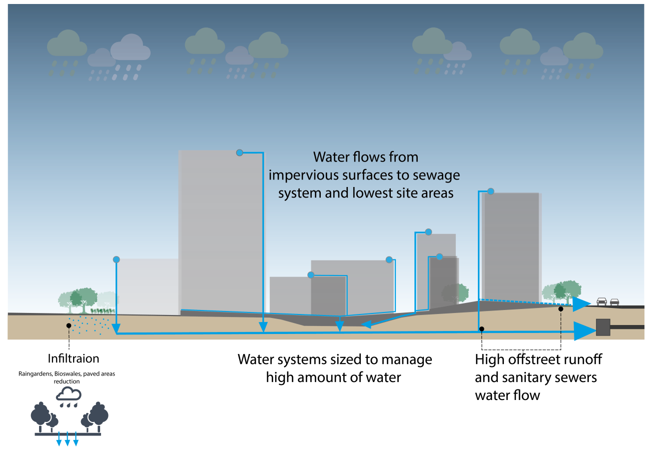

Figure 3a. Conventional Master Plan Approach

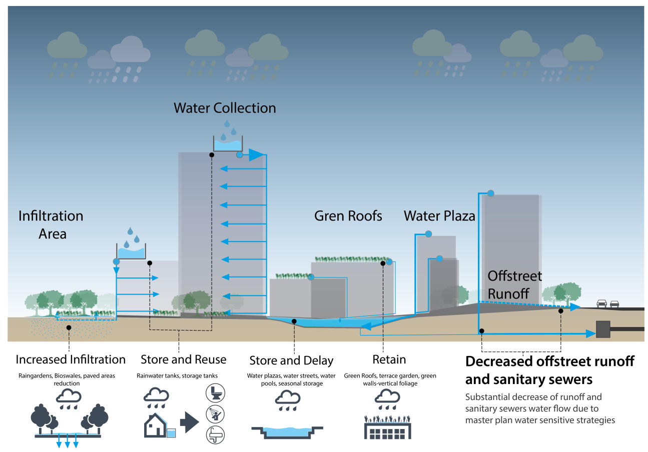

Figure 3b.Water Sensitive Master Plan Approach

Being an open-source tool, this means its in constant development according to the user needs. Nevertheless, its recommended to don't overwrite any implemented methodology but instead test new ones or more detailed calculations as needed.

Methodology

Axolotl is currently designed to use daily precipitation data but there's potential to incorporate hourly data information. Calculations are done applying the Rational Method methodology, but for future development it can be coupled with different single event and continuous simulation methods, such as the Direct Determination Methods, SWMM (*Stormwater Management Model*).

As mentioned before, Axolotl works as an additional tool for Rhinoceros, developed in Python using and creating new Grasshopper components. Figure 4 shows the overall flowchart used for Axolotl water balance calculation.

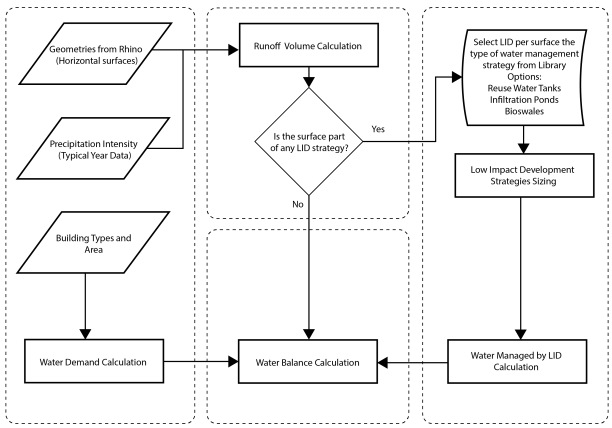

Figure 4.Axolotl flowchart

Axolotl flowchart is based on the previous work done by Fréderic Penet, who developed the MS Excel Tool *Outil Gestion de l Eau*, dividing the calculation into different worksheets. As reported the aim of this tool is to provide a realistic and simple model that provides a quantitative optimization tool for sustainable water management (Penet, 2013). This report will not be focus on the complete water balance calculation methodology explanation but only in those involved to describe the adaptation of this tool to Rhinoceros and Grasshopper.

Input data

Prior to any calculation there should be analysed if trustworthy data is available for the project site location. In the specific case of this project daily data from 620 weather stations reported by CICESE (*Center of Scientific and Higher Education of Ensenada, Mexico*) which is one the most recognized departments of earth sciences studies in Mexico.

An additional *MS Excel Visual Basic* document has been developed to have access to weather stations historical information, compare the recorded data and produce a typical year based on daily profiles from Nuevo León, Jalisco, Baja California and Mexico City.

Axolotl works as explained in the flowchart, with inputs from geometrical surfaces previously designed in Rhinoceros. These surfaces are connected to Grasshopper using *Brep* components, to then being used as part of the master plan runoff calculation using the rational method. Table 1 includes the values for different runoff coefficients depending on the types of surfaces.

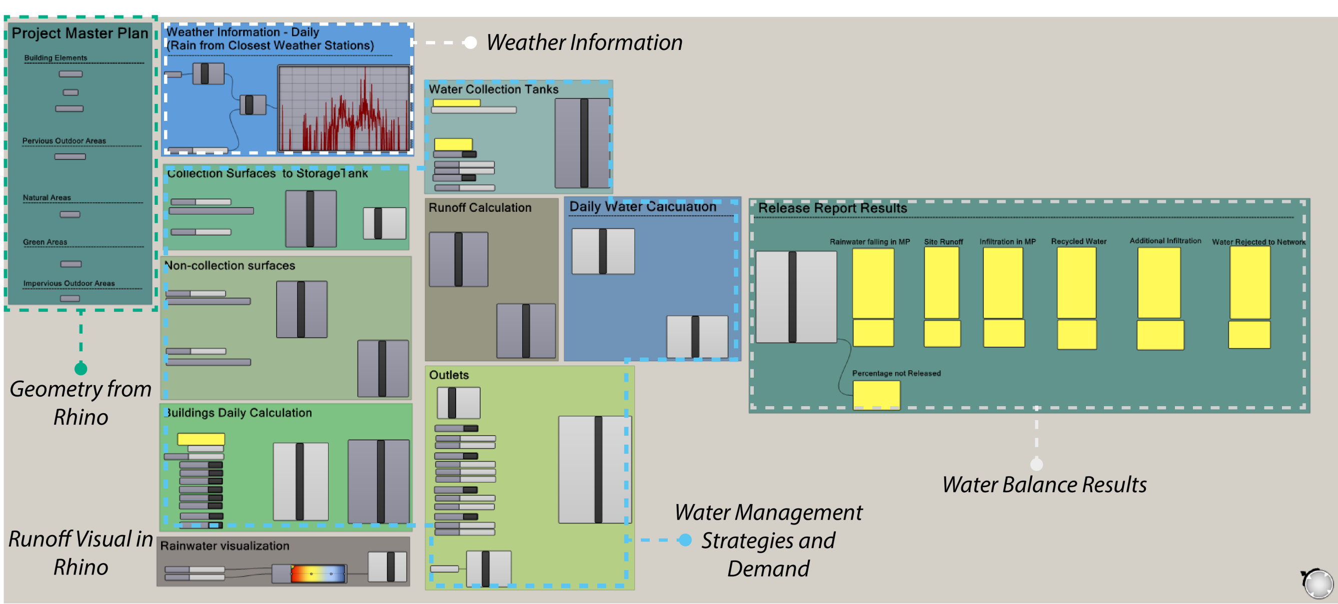

Figure 5.Axolotl Grasshopper Definition

Surface Type	Specifications	R_c
Sloped Roof	Asphalth/Metal/Synthetic	0.88
	Tiles/Slates	0.85
Flat Roof	Asphalt	0.75
	Gravel	0.60
	Intensive Vegetation(20/40cm)	0.25
Other Areas on the plot	Asphalt/Concrete/Metal	1.00
	Slabs/ Pavers with cement joints	0.80
	Grass/Gravel/Dolomite tiles	0.10
	Gardens,Lawns	0.10

Table 1.Runoff coefficients (R_c) for different surfaces.

Water volumes and rates are calculated in the component *"Surfaces Runoff"* to then being used as part of the water balance calculation. This water could be stored in tanks components as part of Axolotl libraries to then being used for building water systems.

Output

Calculations are done following the water balance methodology applied by Penet (Penet,2013) translated from French to English and adapted to Grasshopper components. In general, this methodology is based on the calculation of water falling into the plot daily, and depending on the LID and GI strategies it calculates:

1. *Runoff to off-street*
2. *Water stored and reused*
3. *Water infiltrated (from Rational Method)*
4. *Water Infiltrated (from LID and GI strategies)*
5. *Water rejected to sewerage systems*

In comparison with the source MS Excel File which uses repeated formulas for different cells into their worksheets, in Axolotl the water balance is done in one basic operation performed on each time step using a closed loop function.

Yearly results are displayed numerically. All these results allow designers for potential parametric analysis in an easy and user-friendly environment, that could be adapted according to their design directly from Rhinoceros files and connected to Grasshopper.

Case studies

It's presented the parametric analysis for a theoretical master plan including different water responsive strategies. To show an additional effort to the actual challenges for the citizens of Mexico City, the master plan to be studied is located at Paseo de la Reforma, in the limit of Miguel Hidalgo and Cuauhtémoc. This area, which is one of the most visited and transited areas of the city landscape, is highly vulnerable to high runoff intensity, flash floods and like the rest of the city the soil subsidence is also present (MCG, 2016).

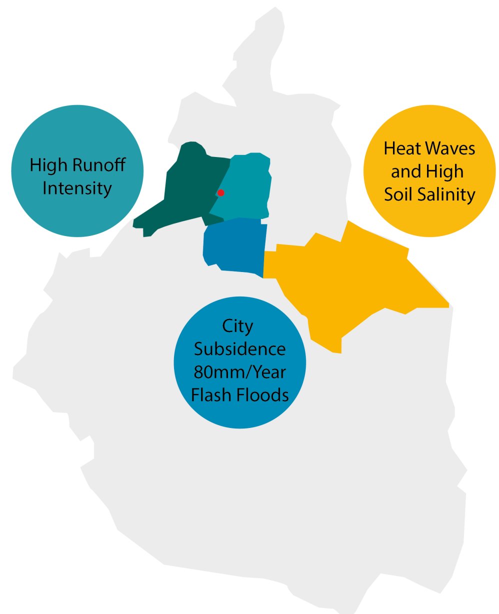

Figure 6. Rainwater Problems Zones (case study location in red)

Figure 7.Master plan for case study, top view

A total yearly precipitation intensity of 780 mm was recorded from the nearest available weather stations, daily intensities below 2.6 mm were not used as suggested by the Environmental Protection Agency(EPA,2009). Figure 7 shows a general overview of the master plan geometries included in the case study.

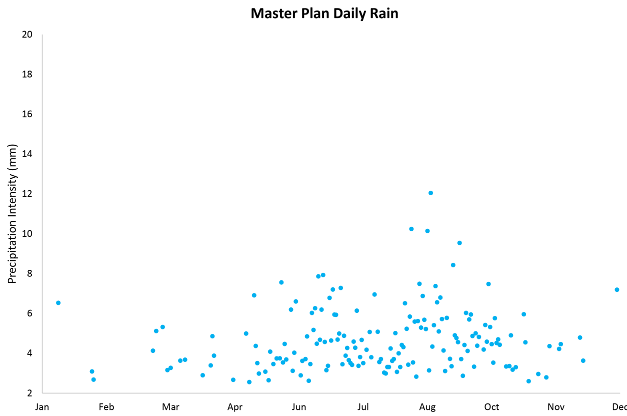

Figure 8. Daily precipitation intensity (mm)

Potential water management LID and GI strategies have been included as part of the project master plan design. Two parametric studies have been done; the first one is related to the project master plan outside areas percentage of pervious and imperviousness, and the second one is related to the whole master plan program water management strategies.

Results

The total exterior area is 88,110 m^2 (excluding buildings footprint); pervious areas are considered as 50 % gravel and 50 % vegetation (R_c = 0.1, 0.05 respectively), and impervious areas are asphalt and concrete based (R_c = 1.0).

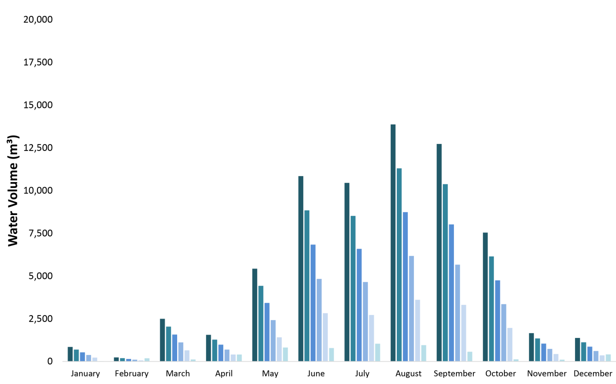

Figure 9.Master plan monthly runoff in exterior areas

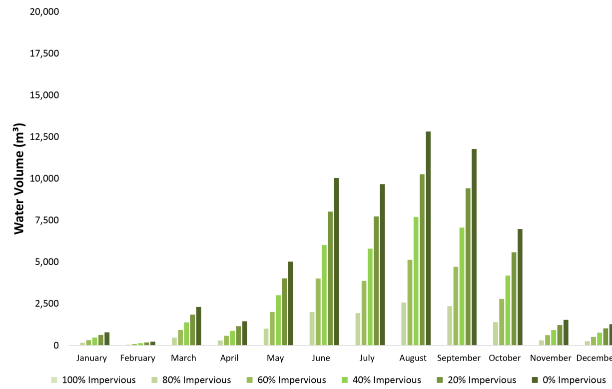

Figure 10.Master plan monthly infiltration in exterior areas

Figures 9 and 10 show the monthly total values for runoff and infiltration. Cumulative yearly runoff and infiltration for each variant are presented in the following Table 2 and Figure 11.

Variants	Area m^2	Cumulative Runoff ($m^3 year$)	Cumulative Infiltration ($m^3 year$)
100 % Impervious	88,110	69,035	0
80 % Impervious	70,488	56,263	12,770
60 % Impervious	52,866	43,492	25,540
40 % Impervious	35,244	30,720	38,315
20 % Impervious	17,622	17,950	51,085
0 % Impervious	0	5,530	63,857

Table 2.Master plan yearly water balance

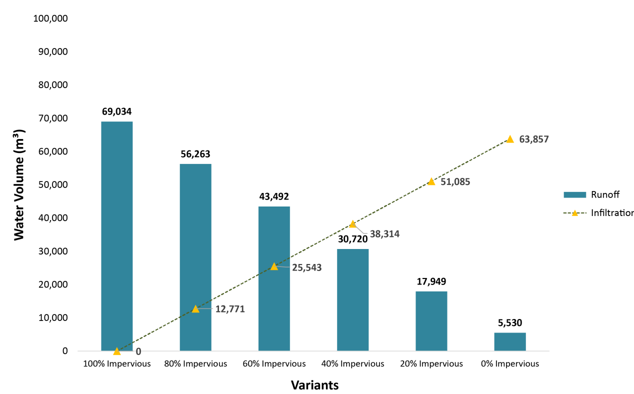

Figure 11.Master plan yearly runoff and infiltration in exterior areas

From these results was decided to include a 60 % of pervious exterior areas, to decrease 56 % the amount of water that would end up in outdoor offstreet areas and sewage networks. From the graph is clearly shown that the methodology applied considers a linear relation between the area impervious ratio and the runoff produced.

Buildings inside the master plan have been grouped into 5 individual storage systems for recycled water. Table 3 presents the total potable water demand for each group of buildings and the potential volume to be recycled.

Buildings group	Type	Gross Floor Area (m^2)	Yearly water demand (m^3)	Yearly rooftop runoff (m^3)
Group 1	Offices	210,000	47,192	350
	Restaurant	10,000		
Group 2	Residential	45,000	42,507	400
	Gardens	500		
Group 3	Residential	32,500	21,990	312
	Offices	1,000		
Group 4	Residential	39,000	26,165	360
Group 5	Offices	65,000	12,103	526

Table 3.Master plan water summary

The storage systems capacity has been oversized to capture 20 % of the total yearly runoff volume coming from each building rooftop in each group. Being an exercise, this volume has been intentionally increased to ensure all the water that can be captured is ideally collected.

As described before in the *Case Studies* section, four parametric studies were implemented on the master plan to quantify each LID and GI strategy improvement to the water management program. The following figures will show in consecutive order the strategies listed below:

1. Increased infiltration: Includes the results from the parametric study for pervious and impervious exteriors areas.

2. Store and reuse: Includes the previous strategy for increased infiltration, and additionally uses the described 5 rainwater storage tanks for water reuse.

3. Store and delay: Includes the previous strategies and is considered a water plaza in the center of the master plan plaza. The water plaza pool total volume capacity is 520m^3 with a discharge rate of 0.5m^3/hr.

4. Store increased:As variant 3, includes the previous strategies described in variant 1 and 2 but the water volume capacity for this central pool is increased to 4,800m^3 with a discharge rate of 3.5m^3/hr.]

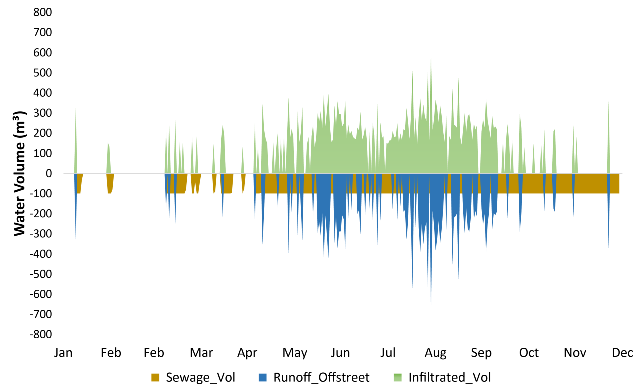

Figure 12.Variant 1, increased infiltration

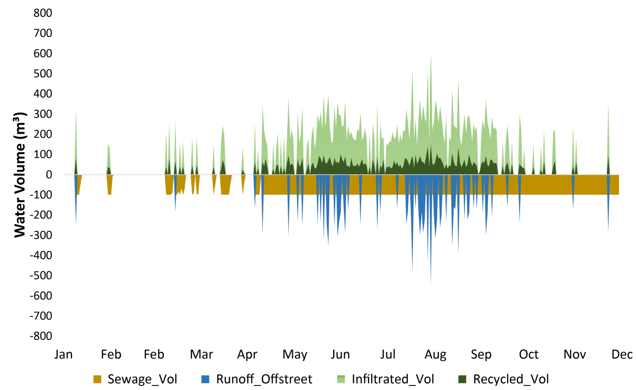

Figure 13.Variant 2, store and reuse

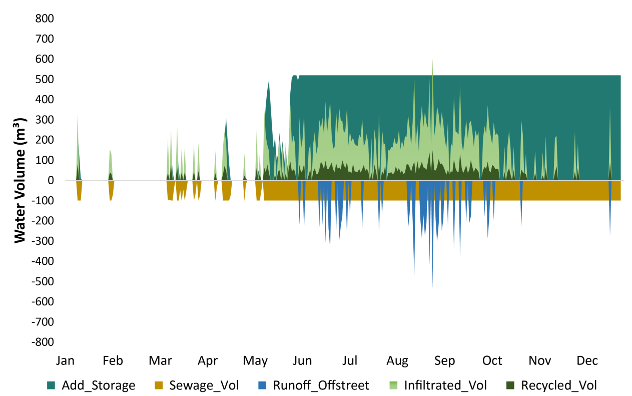

Figure 14.Variant 3, store and delay

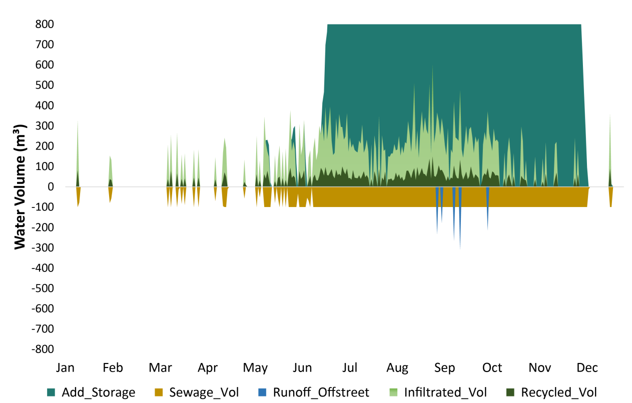

Figure 15.Variant 4, store increased

As the figures show, there's a significant decrease in water runoff as each one of the water management strategies have been applied; the amount of water rejected to the sewage network is included as part of the conventional drainage system sizing, which has a rate of 0.1 *liters/second/ha* (this value must be minimized or even cancelled when feasible). Table 4 shows the yearly water volume balance calculation for each variant on site.

Variants	Total water managed (m^3year)	Total runoff (m^3year)	Total water to sewage (m^3year)
Increased infiltration	38,852	23,604	27,512
Store and reuse	48,488	14,785	26,695
Store and delay	51,740	11,978	26,250
Store increased	67,950	98	21,920

Table 4.Yearly water balance summary per variant

Outdoor comfort

An innovative and state of the art methodology to calculate the effect of water bodies surfaces has been designed and developed in parallel to quantify the impact in outdoor comfort performance in exterior areas. Outdoor comfort UTCI (Universal Thermal Climate Index) has been selected as the local variable describing projects outdoor comfort.

This index need to fulfill certain input data requirements such as air temperature, water vapor pressure, wind velocity, mean radiant temperature of surfaces surrounding the area in study (including solar radiation), metabolic rate and clothing (Jendritzky,2002).

An exterior water plaza has been designed to make an outdoor comfort study; the maximum volume of water that can be managed by this pool is 4,800 m^3. Figure 16 shows the water plaza location, which would receive water from Group 1 buildings rooftop.

The purpose of the study is to calculate and compare the UTCI values in a conventional concrete plaza and a water plaza with available water depending on the precipitation intensity through the year.

Figure 16.Water plaza location, top view

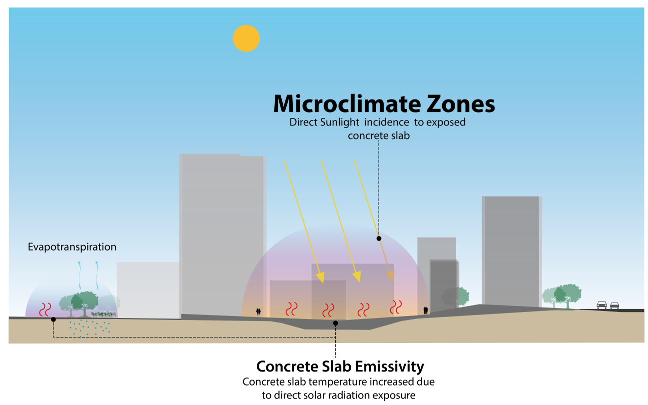

Figure 17a.Concrete plaza microclimate, section view

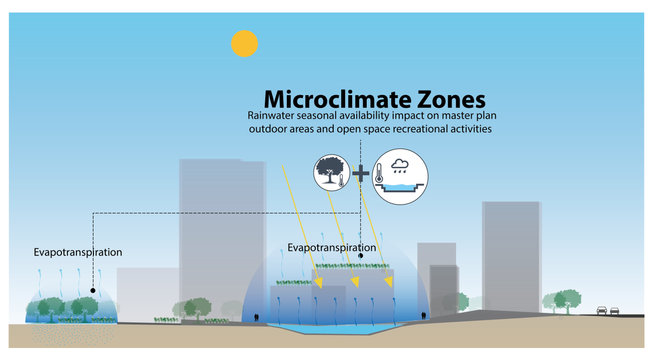

Figure 17b.Water plaza microclimate, section view

UTCI calculations were done in TRNSYS, using as interface TRNLizard-Grasshopper. Precipitation data was discretized from daily to hourly data, dividing the total amount of daily rain into 24 hours to calculate approximately the periods of the year when the water pool expects to have rainwater. Only during these periods of time, the radiant temperature on the concrete plaza changes to the radiant temperature of the water surface on the water pool.

Three different TRNSYS types were used to calculate the water balance inside the pool as listed below:

- **Type344** is used as an empty outside pool was used to calculate the hourly amount of water evaporation during the year.
- **Type9** is used to access the hourly water runoff expected from the rooftop surfaces (to later be used as coming inflow to the pool).
- **Type93** stores the hourly results of the water balance inside the pool, that could be basically calculated from the following equation:

$$\sum_{i=0}^{8759} Rw_i + (Rw_{i+1} - Ep_{i+1} - Dr_{i+1})$$

Where:

Rw = Rainwater inflow to pool (m^3/hr)

Ep = Evaporation rate if water inside the pool (m^3/hr)

Dr = Additional drain system for the pool (m^3/hr)

i = timestep (hr)

The water balance is then calculated to be incorporated as part of the inputs for the outdoor comfort simulation. The following figure shows the water availability and the surface temperature depending on the water inside the pool for the case study.

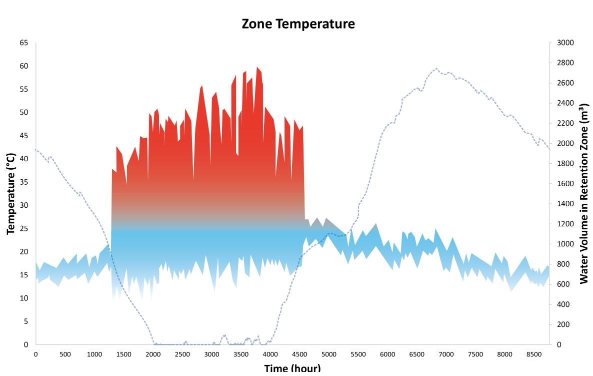

Figure 18.Hourly water plaza surface temperature

The blue dotted line is showing the water volume stored through the year inside the water plaza, as is shown, the plaza its empty for approximately 2,000 hours (from April-June). During this time the surface of the exposed concrete in the water plaza rises to almost 60° C, and cools down to 10°C. The rest of the year the graphs is showing the water surface temperature, which is in the range of 10 to 30° C.

This change on the surface temperature will produce an effect on the total mean radiant temperature, as shown in Figure 19a and Figure 19b.

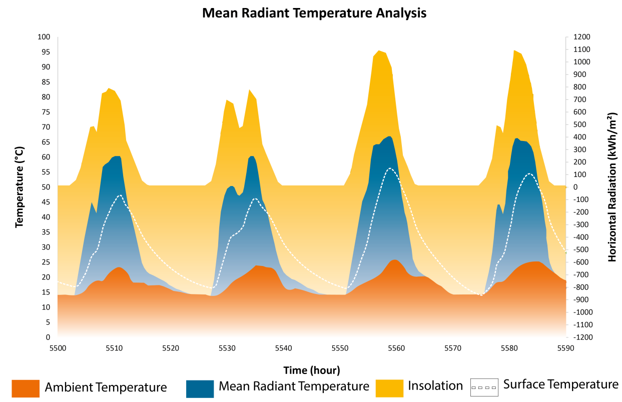

Figure 19a.Mean radiant temperature, exposed concrete plaza

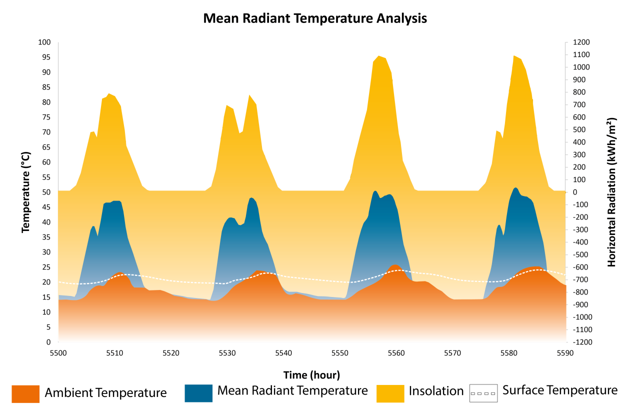

Figure 19b.Mean radiant temperature, water plaza

A TRNLizard definition in Grasshopper was used to calculate UTCI values in the water plaza. Boundary conditions were defined in Rhinoceros - Grasshopper, to be used as input for the thermal analysis as shown in figures 20a and 20b.

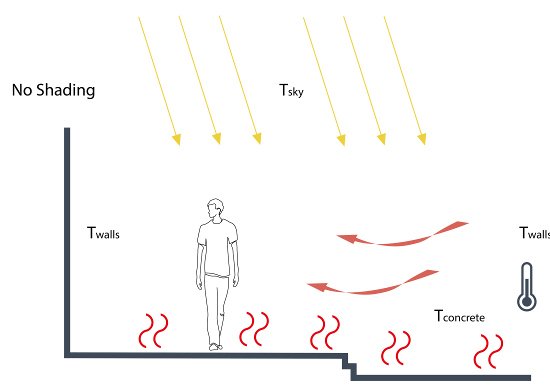

Figure 20a.Boundary conditions, concrete plaza

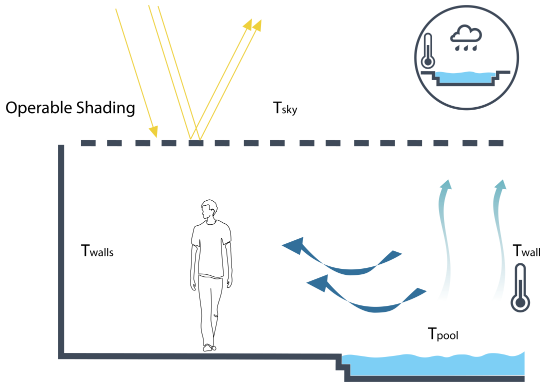

Figure 20b.Boundary conditions, water plaza

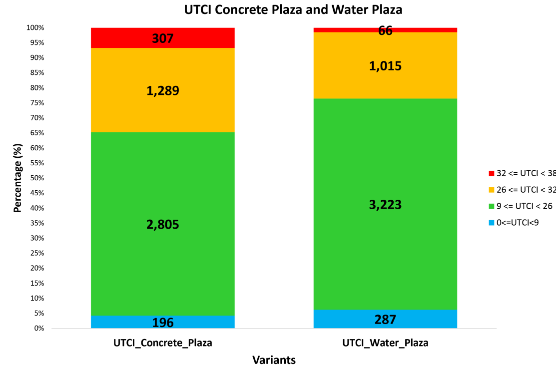

Figure 22.UTCI values yearly comparison, water and concrete exposed plaza

Figures 21a and 21b show the results for the UTCI monthly distribution values, on the water and concrete plaza.

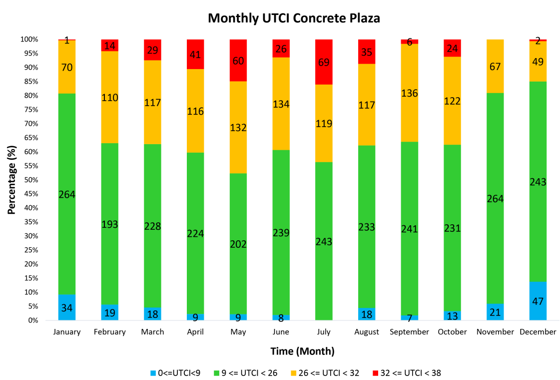

Figure 21a.UTCI values monthly distribution, concrete plaza

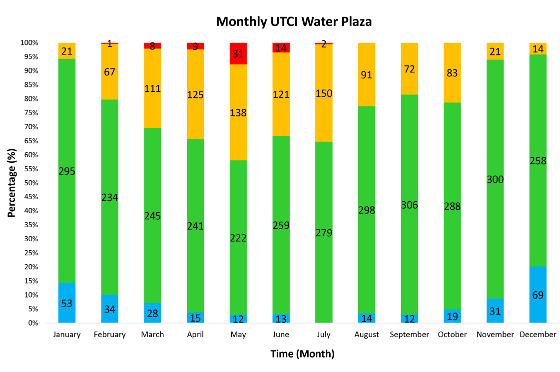

Figure 21b.UTCI values monthly distribution, water plaza

As can be noticed during the months using the water pool there's an increase on the hours with UTCI values between 9 to 32°C. Figure 22 shows the total yearly comparison for both study cases.

Conclusions

Axolotl is a new tool for rainwater management that could be used as part of the design process for new projects where rainwater management is a potential resource for resiliency, savings and comfort benefits. The project demonstrated that through the incorporation of water responsive LID and GI strategies the effect in water released as runoff to the city can be decreased in 100 % if desired.

Axolotl main purpose is to allow designers to use a friendly environment tool to include rainwater in their process of design. It could be seen as an alternative response for one of the long list of problems related to urban development in Mexico, and it could also be seen as a change of perspective for rainwater in peoples mind, becoming a solution for improving peoples quality of life.

I would like to thank to Transsolar Klimaengineering for giving me the opportunity to grow as a professional during the development of this project, and during all this year of this amazing experience as part of the Transsolar Academy. Special thanks to the Academy fellows, Petru Du Toit, Pallavi Chidambaranath, Nikki A. Panaligan, Elmer Gutierrez, Achilles Ahimbisibwe, for being an incredible team, to Christian Frenzel, Tommaso Bitossi, Monica Lauster, Sabine Gröger, Diego Romero and Vu Hoang for all your support in the development of this project.

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