(02-027) - URBION: Adapting Urban Spaces to Climate Change through a Catalog of Components and Solutions

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Adapting urban spaces to climate change is crucial for enhancing the habitability of cities. Therefore, efficient urban planning that prioritizes comfort is essential. To achieve this, architects, engineers, and urban planners involved need reference catalogs on urban components that ensure optimal interaction between design and climate conditioning. In this context, the URBION tool aims to predict the behavior of urban components through a methodology that evaluates specific case studies. Urban spaces are typified as rooms, and coverings, soils under these, and adjacent soils are modeled. The catalog includes both conventional and innovative components, which allows for a systematic analysis of their properties and design variables under various meteorological conditions. The properties considered include albedo, transmissivity, and solar overheating of the components. Additionally, URBION also evaluates the PET comfort index, which helps determine the impact on the well-being of the occupants of the spaces under design. As a result, a digital design guide is generated that provides information on key variables, analyzes their range of variation, and determines their influence in terms of comfort.

Keywords: Climate Change; Urban Design Tool; Outdoor Thermal Comfort; Guide to Urban Components; Catalog of Urban Solutions

URBION: Adaptando Espacios Urbanos al Cambio Climático a través de un Catálogo de Componentes y Soluciones

La adaptación del espacio urbano al cambio climático es crucial para mejorar la habitabilidad de las ciudades. Por tanto, una planificación urbana eficiente que priorice el confort es esencial. Para lograrlo, los arquitectos, ingenieros y urbanistas involucrados necesitan de catálogos de referencia sobre componentes urbanos que aseguren una interacción óptima entre diseño y acondicionamiento climático. En este contexto, la herramienta URBION busca predecir el comportamiento de componentes urbanos mediante una metodología que evalúa casos de estudio específicos. Los espacios urbanos se tipifican como estancias, y se modelan coberturas, suelos bajo estas y suelos adyacentes. El catálogo incluye componentes tanto convencionales como innovadores, lo que permite un análisis sistemático de sus propiedades y de las variables de diseño bajo distintas condiciones meteorológicas. Las propiedades consideradas incluyen el albedo, la transmisividad y el sobrecalentamiento solar sobre los componentes. Además, URBION también evalúa el índice de confort PET, lo que permite determinar el impacto en el bienestar de los ocupantes de los espacios objeto de diseño. Como resultado, se genera una guía de diseño digital que informa sobre las variables clave, analiza su rango de variación de estas y determina su influencia en términos de confort.

Palabras clave: Cambio Climático; Herramienta de Diseño Urbano; Confort Térmico en Exteriores; Guía de Componentes Urbanos; Catálogo de soluciones urbanas.

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1. Introduction

The increasing urgency of climate change highlights the importance of effective urban planning in large cities. High temperatures and limited protection from solar radiation turn urban surfaces into potential heat absorbing and heat retaining elements, creating an environment that compromises the habitability of the city given the high temperatures reached (Santamouris, 2014, 2023). This situation is aggravated by anthropogenic heat, which contributes to increased heat stress in public space by reducing the comfort of its residents (Chow et al., 2014). The climate challenge faced by cities requires a coordinated response from local governments and departments, and it is vital to address these challenges to ensure healthier, more sustainable, and resilient urban environments(Li et al., 2017; Ren et al., 2021).

The main mitigation measures focus on cooling cities through passive techniques using vegetation and water(Wang et al., 2016). Vegetation reduces heat absorption and improves air quality through evapotranspiration. Water plays a key role through its natural cycle and climate regulation, carrying out heat transfer from surfaces with higher temperatures by transporting water in the form of vapour (Doulos et al., 2004; Santamouris et al., 2011). The most used techniques include green roofs and coverings, permeable pavements, low albedo building elements, irrigation systems, urban heat exchangers and evaporative cooling technologies.

The creation of effective methodologies in the context of urban planning and adaptation requires the creation of a catalogue of components(Garshasbi et al., 2020). These components are referred to as physical elements or possible solutions grouped according to their characteristics and/or properties. A correct definition of this catalogue is essential to identify and evaluate available adaptation options given an urban environment to be studied. Each component or implemented solution allows, to a certain degree of effectiveness, mitigating the heat island effect, cooling the city, reducing vulnerability to heat stress and improving air quality and community resilience.

The research community has limited methodologies and validation models that facilitate urban planners' ability to replicate successful adaptation projects (Nakata-Osaki et al., 2018; Santamouris et al., 2017). In addition, there is a lack of understanding of how each solution performs in various situations considering the modification of different variables in a systematic way, including design variables and meteorological data. This limitation makes it difficult to make decisions and implement techniques for urban adaptation. This is why it is essential to develop calculation tools based on a decision-making methodology to evaluate and validate strategies at the urban level.

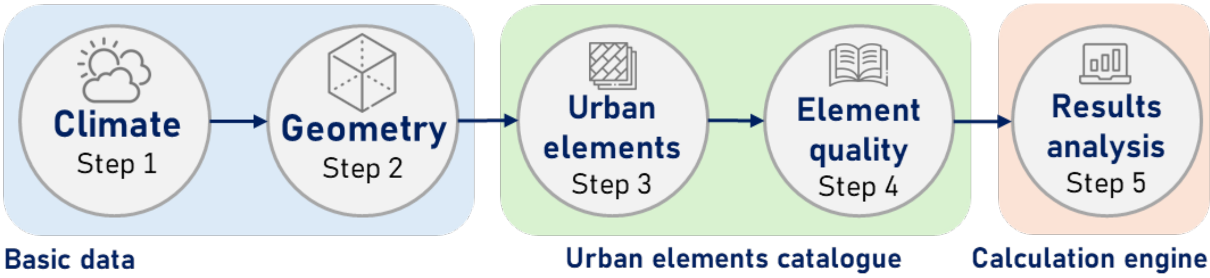
2. Objectives

The aim of the present work is focused on the creation of a working tool that allows decision making thanks to a catalogue of urban components and solutions, implementing elements and systems capable of modifying the climate conditions of an open space. To this end, the URBION tool was created, which allows decisions to be made by comparing urban elements and their repercussions on the thermal comfort of people. The methodology followed by the tool is simple and consists of few steps, helping the user to make effective and quick decisions. The study is carried out on a stay area to use the tool for the adaptation of spaces for rest, restoration, short and random shows, where the metabolic activity of the person who inhabits it is sedentary. To conclude the analysis and reinforce the understanding of the tool, a case study is detailed through which it has been possible to identify intervention options and optimise the actual sizing of urban elements, evaluating their viability and effectiveness in the long term.

3. Methodology

URBION is possible thanks to the definition of an extensive catalogue of components present in the urban environment. It focuses on establishing an exhaustive classification and breakdown of solar coverings, pavements and soils, considered to be the most important in alleviating high temperatures and improving the comfort of the inhabitants. The classification and breakdown of physical and thermal characteristics has been made possible through an extensive literature review. As a result, an intuitive step-by-step process has been established, focusing on a calculation process capable of bringing together climatic data, geometry, and the characteristics of urban elements (Figure 1). The geometry of the urban space has been studied in detail, breaking it down into three different categories: passage areas, living areas and adjacent areas.

Figure 1: URBION tool calculation methodology



3.1 Urban components catalogue

The catalogue of components is made up of different types of solar coverings and pavements. The classification has allowed a breakdown of each of their properties, which has been very useful for the calculation process and the analysis of the results that has been developed. The elements and materials analysed have been prioritised because a correct design and planning benefits the comfort of the inhabitants (Zou & Zhang, 2021). The coverings provide quality shade and block direct solar radiation on the occupant. The choice of flooring type influences the comfort of people in sunny areas or immediately adjacent to a passage or living area. The contribution to be weighted is based on reflected solar radiation which is lower with dark flooring colours. Meanwhile the long wavelength radiation is lower with light colours. The property studied by the research community for coverings is transmissivity, which measures their ability to block solar radiation. Meanwhile for pavements it is albedo, which measures the ability to reflect solar radiation, absorbing the least amount of heat energy and therefore reducing the surface temperature.

In this context, Table 1 and Table 2 show a summary of the classification that has been carried out for both elements. The coverings (shown in Table 1) are distinguished between conventional and thermally activated ones. The latter consist of systems that enable the surface temperature to be reduced by means of water. The floor coverings (shown in Table 2) are also classified into conventional and special ones. The special floorings are the so-called cold floorings, ponds or solar panels, which have different thermal characteristics. In both cases, the properties studied are:

- Transmissivity.
- Reflectivity (albedo).
- Mean water temperature.

Table 1: Catalogue of covers

	Conventional covers	Properties
Textiles	Covers classified according to their perforation (without, 2% and 4%), their continuity (continuous or discontinuous) and their openness.	Transmissivity and reflectivity
Wood	Covers classified according to their opacity, continuity and perforation (10% and 20%). Louvres are also included, detailing their orientation (South orientation) and their opening in degrees (30º, 45º, 60º).	
Concrete	Covers classified according to their opacity and continuity.	
Vegetation	Covers classified according to transmissivity (5%, 10% and 15%).	
	Special and thermally activated covers	**Properties**
Textiles	Coverings classified in the same way as conventional coverings, considering thermal activation by water irrigation.	Transmissivity, reflectivity and mean temperature of activation water
Wood	Slat coverings classified according to their orientation and opening in degrees, considering thermal activation by falling film with water.	
Concrete	Covers classified according to their opacity and continuity, considering thermal activation by falling film.	
Photovoltaic panels	Covers classified according to their transmissivity (5%, 10% and 15%), continuity, perforation (10% and 20%) and yield (8% and 15%). Thermal activation by falling film is considered.	

Table 2: Catalogue of pavements and soils

	Conventional pavements	Properties
Impermeable	The materials selected were concrete, asphalt, terrazzo, wood, and ceramics. They are considered based on a resistant structure.	Transmisividad y reflectividad
Permeable	The materials selected are porous concrete, stone paving, terrazzo, ceramic tiles and paving stones.	
Vegetation	Impermeable parts are considered with vegetation in different quantities (20%, 40% and 60%), as well as a continuous vegetation cover.	
	Special pavements	**Properties**
Cool pavements	Cold pavements are classified as porous and non-porous, taking into account thermal activation by water.	Transmissivity, reflectivity and mean temperature of activation water
Photovoltaic panels	Pavements classified according to their transmissivity (5%, 10% and 15%), continuity, perforation (10% and 20%) and performance (8% and 15%). Thermal activation by falling film is considered.	
Ponds	They are classified according to depth (shallow <2 metres, and intermediate between 2 and 5 metres).	

3.2 URBION tool

URBION calculates a case study given a climate and a geometry, selecting the urban element to be studied and defining the quality of the rest of the materials that make up the case. Figure 2 shows the tool's start-up screen, where the 4 steps on which the methodology is based are shown. The drop-down associated with the climate allows selecting the city in which the case study is located, setting the humidity to provide more detailed information. The climate associated with each of the different provinces is obtained by studying a representative hot day. These data are extracted from the SIAR climate stations (Ministerio de Agricultura, 2024). For a given location, the hottest day of the last year is defined considering the months of May to September. Key data include dry air temperature, wind speed, wind direction and solar radiation for clear days. The humidity to be selected can be low (considering an absolute humidity lower than 6 g/kg), medium (between 6 and 10 g/kg) and high (higher than 10 g/kg).

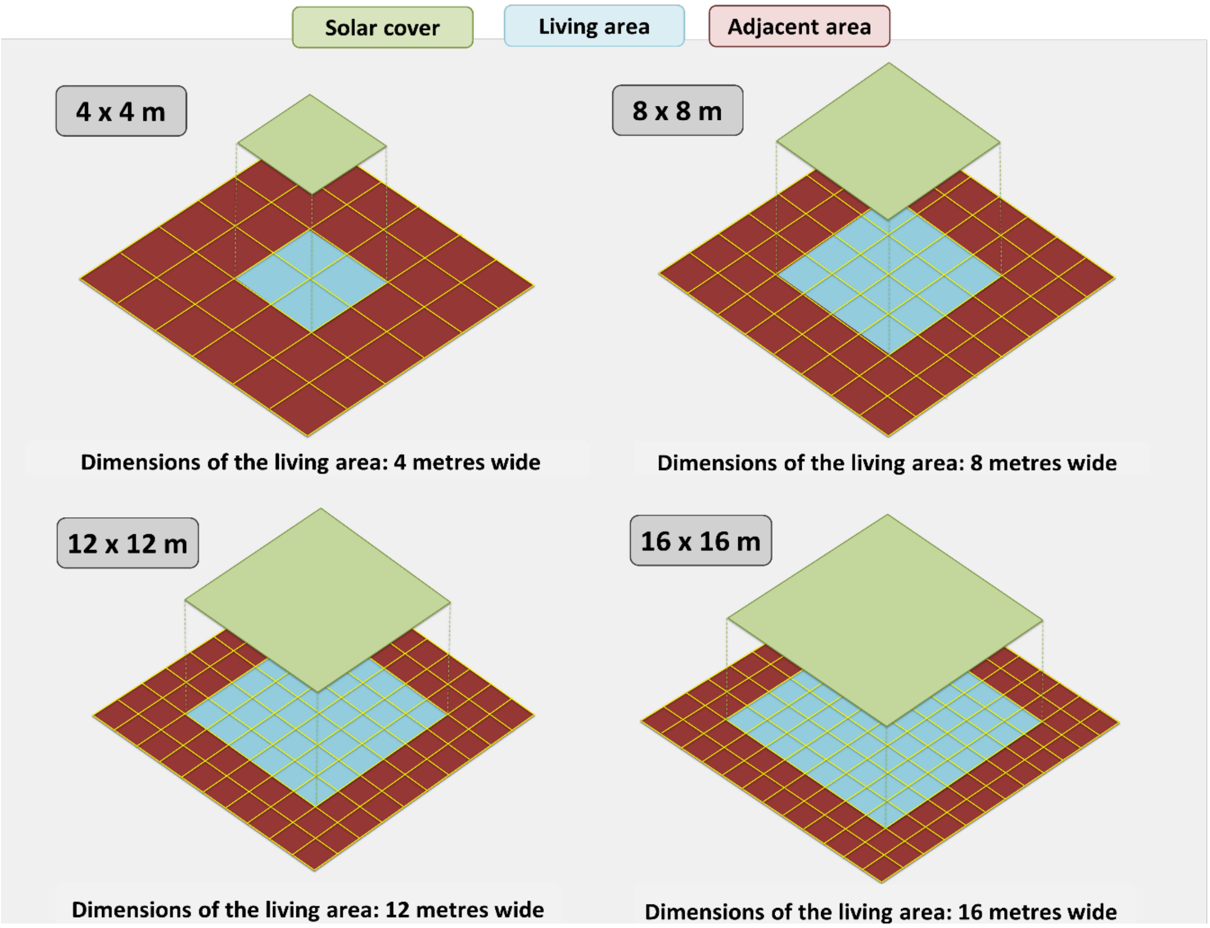
Figure 2: URBION home screen

The second step focuses on defining the properties of the living area. Figure 3 considers the quadrangular case studies divided into different zones of interest:

- Stay zone (blue colour): Places destined for rest or restoration, which offer relief by being in the shade offered by a hedge (green colour). The occupation of the area is high given the climate studied and the person's need for shelter from the sun. Whatever the specific use of these zones, the activity of the visitor can be considered low (resting and sedentary for met = 1), medium (light activities such as walking or standing, for met values between 1 and 2) or high (high impact, running, jumping, for met values above 2) (ASHRAE, 2017; Fanger, 1967). The dimension of such zones shall cover areas with a maximum characteristic length of 16 metres. Different dimensions of the standing area have been established, with a choice between dimensions of 4 x 4, 8 x 8, 12 x 12 and 16 x 16 metres.

- Adjacent area (red colour): Connecting spaces and passageways that connect the living areas. It is considered that the occupation of the adjacent zone is low or null because it is influenced by the direct incidence of solar radiation and high surface temperatures.

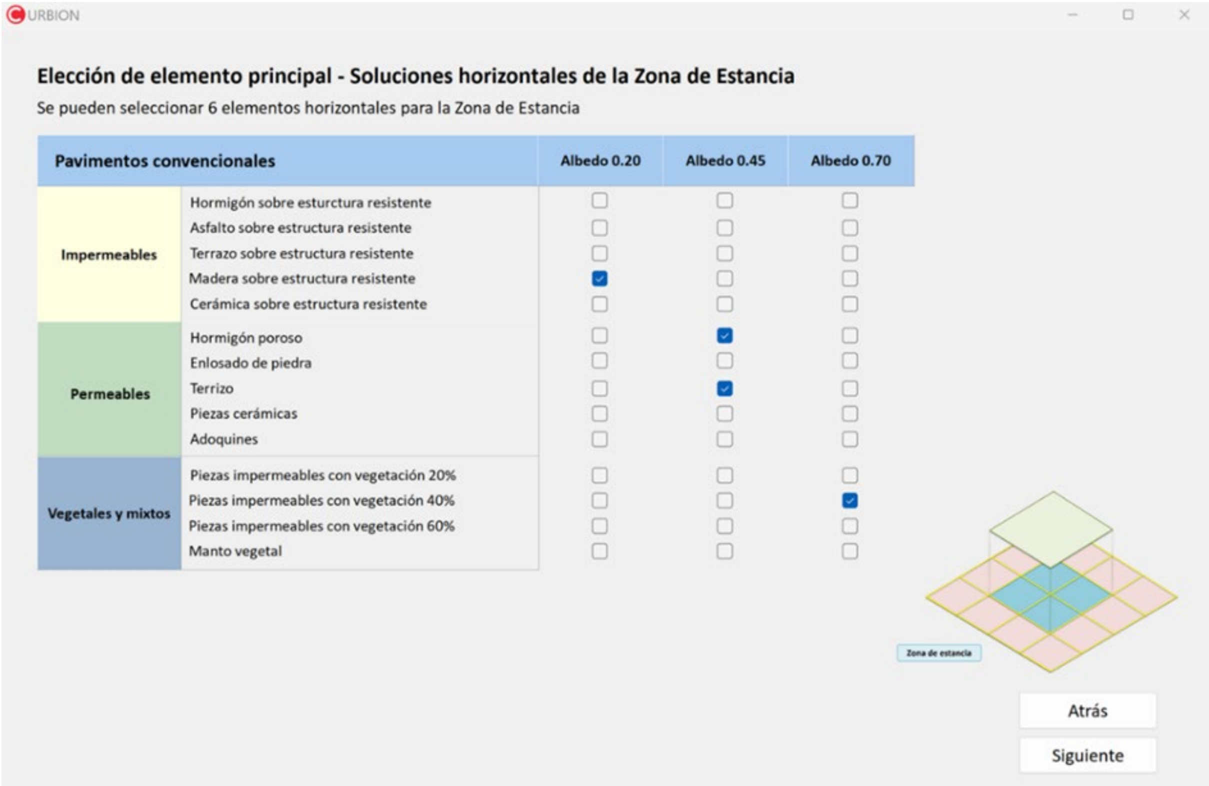
Figure 3: Living areas define in URBION tool



The third step allows the selection of the main urban element to be studied. It is only possible to select a single element between coverings, living area pavements and adjacent area pavements. In the meantime, the user has the possibility to study up to 6 different materials once an element is selected, comparing the results with each other. Figure 4 shows the material selection process for the case of selecting the living area paving as the main element. Regardless of whether the choice of coverings or paving is made, the user must select the materials according to the albedo that suits his needs, which takes 3 values: an albedo of 0.2 for those materials with dark colour and low reflectivity; 0.45 for those materials with intermediate colour and reflectivity; and 0.70 for those materials with low colour and high reflectivity (Elnabawi et al., 2023; Salata et al., 2015).

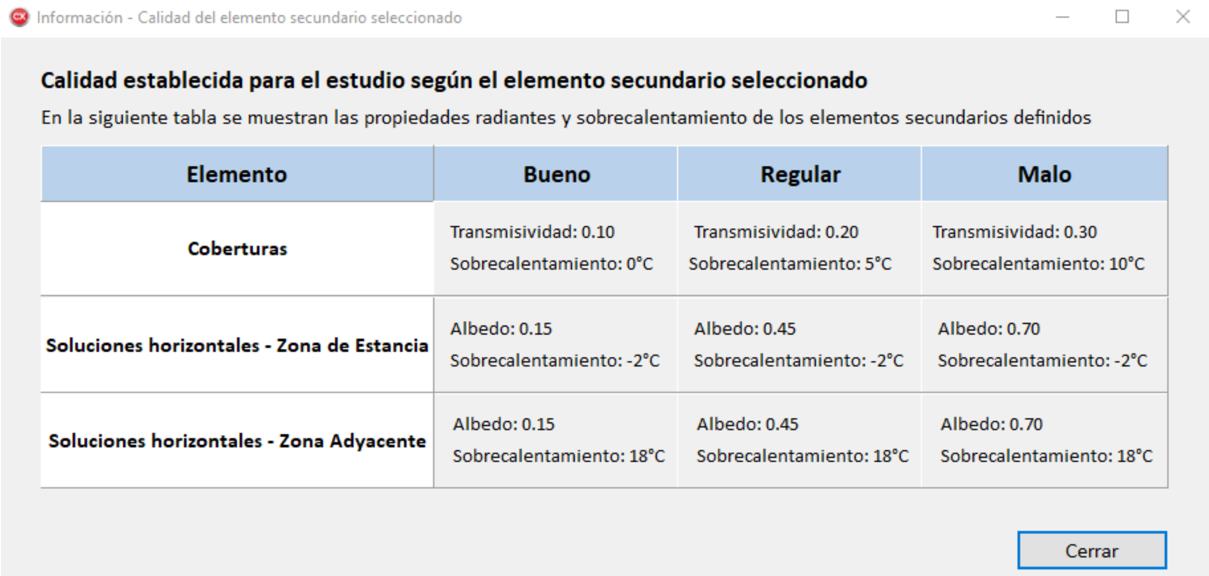
The catalogue of components is used when choosing the materials for urban elements. In cases where conventional paving is intended to be used, the reduction of incident solar radiation caused by the coverings is the dominant effect, which homogenises surface temperatures considerably regardless of the materials and/or colours used. On the other hand, the choice of flooring type can only influence comfort in sunny areas immediately adjacent to a living area. For this reason, in the analysis of the floorings in the living area, only conventional floorings are considered, while in the adjacent areas, conventional and special floorings are considered (Departamento de Ingeniería Energética y Mecánica de Fluidos (Universidad de Sevilla), 1994).

Figure 4: Selection of the main elements to be analysed



The fourth and last step is to select the quality of the rest of the elements that make up the living area. By default and following the transmissivity and reflectivity values in the component catalogue, the user can define the rest of the materials as poor, average and good quality. Figure 5 shows a user help set in the tool itself (Information button in Figure 2), informing the user about the values of transmissivity, albedo and overheating for each of the mentioned qualities. Overheating is a property common to both elements, being the increase in temperature that can be reached due to solar radiation on a clear day (Santamouris, 2014).

Figure 5: Quality of urban elements


Información - Calidad del elemento secundario seleccionado

Calidad establecida para el estudio según el elemento secundario seleccionado

En la siguiente tabla se muestran las propiedades radiantes y sobrecalentamiento de los elementos secundarios definidos

Elemento	Bueno	Regular	Malo
Coberturas	Transmisividad: 0.10 Sobrecalentamiento: 0°C	Transmisividad: 0.20 Sobrecalentamiento: 5°C	Transmisividad: 0.30 Sobrecalentamiento: 10°C
Soluciones horizontales - Zona de Estancia	Albedo: 0.15 Sobrecalentamiento: -2°C	Albedo: 0.45 Sobrecalentamiento: -2°C	Albedo: 0.70 Sobrecalentamiento: -2°C
Soluciones horizontales - Zona Adyacente	Albedo: 0.15 Sobrecalentamiento: 18°C	Albedo: 0.45 Sobrecalentamiento: 18°C	Albedo: 0.70 Sobrecalentamiento: 18°C

Cerrar

3.3. Calculation process

The calculation process involves the comparison of different scenarios through modelling using equations. These equations constitute what is known as a mathematical model, which can be used to predict the behaviour of the components and systems in any given situation. The models that simulate the thermal behaviour of coverings and pavements are highlighted, as well as the comfort model of thermal regulation of the human body.

Equation 1 and 2 illustrate the modelling process to characterise a single envelope (Departamento de Ingeniería Energética y Mecánica de Fluidos (Universidad de Sevilla), 1994; Incropera et al., 2018). Together with the climate and geometric data, the model calculates the surface temperature value of the envelope (T_c), which is the one that affects the comfort of the occupants of the living area. The balance on the coverage includes the absorbed radiation ($\alpha_c \cdot Q_s$), the convection with the air (Q_{cv1}, Q_{cv2}) and the radiant exchange with the surrounding surfaces (Q_{rad}). The tool informs the user about the maximum overheating reached during the representative day of study, providing an additional integrated value for 24 hours.

$$\alpha_c \cdot Q_s = Q_{cv1} + Q_{cv2} + Q_{rad} \quad (1)$$

$$\alpha_c \cdot Q_s = h_{c1} \cdot (T_c - T_{as}) + h_{c2} \cdot (T_c - T_{ai}) + \sum C_{cj}\,(T_c^4 - T_j^4) \quad (2)$$

Where Q_s is the sum of direct and diffuse solar radiation, α_c is the absorptivity of the solar cover, h_{c1} y h_{c2} are the convective film coefficients at the top and bottom of the cover, respectively. Similarly, T_{as} y T_{ai} are the air temperatures at the top and bottom of the cover. C_{cj} are the radiative exchange coefficients of the canopy with the surfaces seen by the canopy including the sky and pavement. T_j is the temperature of the surfaces seen by the envelope.

In addition, Equation 3 and 4 illustrate the surface balance performed on the pavement to establish its surface temperature (T_p) (Departamento de Ingeniería Energética y Mecánica de Fluidos (Universidad de Sevilla), 1994). The surface balance considers the direct and diffuse radiation on the pavement (Q_s), the heat flow by conduction (Q_{cd}), the convective flow in the ambient air (Q_{cv}), the long wavelength radiant exchange (Q_{rad}) and the moisture evaporation (Q_e). The tool informs the user about the maximum overheating reached by the pavement typology, as well as an integrated value for the 24 hours of the studied day.

$$\alpha_p \cdot Q_s = Q_{cd} + Q_{cv} + Q_{rad} + Q_e \quad (3)$$

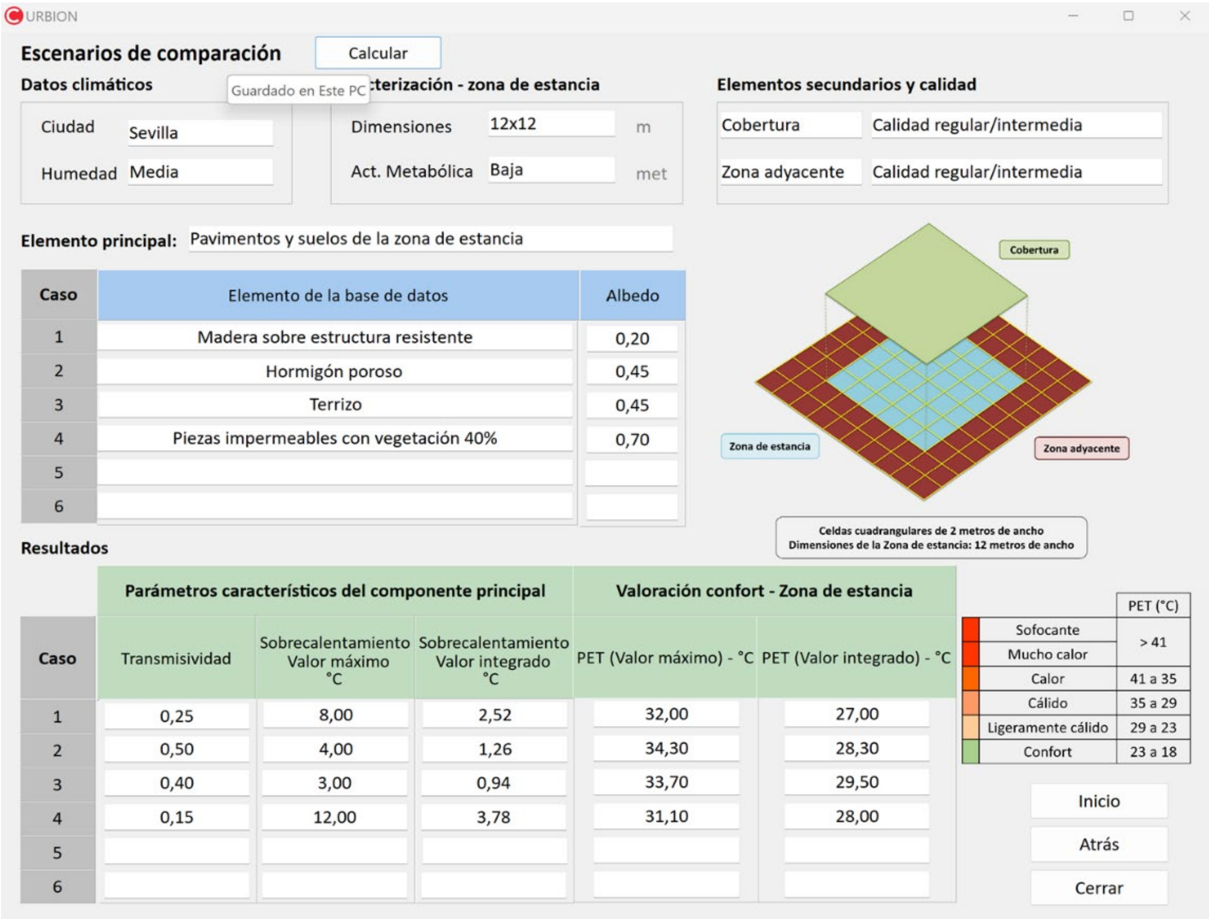
$$\alpha_p \cdot Q_s = \left(-k \cdot \frac{dT}{dt}\right) + h_p \cdot (T_p - T_a) + \sum C_{pj}\,(T_p^4 - T_j^4) + Q_e \quad (4)$$

Where Q_s is the sum of direct and diffuse solar radiation, α_p is the absorptivity of the pavement, h_p is the convective film coefficient. Likewise, T_a is the air temperature, C_{pj} are the radiant exchange coefficients of the pavement with the surfaces seen by the pavement including the sky and the solar cover, T_j is the temperature of the surfaces viewed by the pavement. The term $-k \cdot \frac{dT}{dt}$, represents the Fourier law of conduction heat flow, where k is the ground conductivity and $\frac{dT}{dt}$ is the ground differential over time.

Finally, the tool considers the calculation of the PET comfort index to establish the level of thermal stress of the person depending on the chosen adaptation element. This index shows the person's thermal sensation in temperature values, based on a two-node model of human thermoregulation (Walther & Goestchel, 2018). This model considers the internal and skin temperature parameters of the person, as well as the humidity of the environment in which it is considered. In this case, the steady-state calculation model used by the IMEM "Instationary Munich Energy balance Model" (Höppe, 1999) is used and calculated using Python programming.

Figure 6 shows the results screen to compare the retrofit options after calculation. A summary is made of the defined initial data, the characterisation of the living area and the quality of the secondary elements. The results are divided into characteristic parameters of the chosen main component and the comfort rating for an occupant in the chosen living area. Thanks to this data, the user of the tool can analyse a total of 6 different urban elements thanks to the comparison by overheating and their impact on the occupant's comfort.

Figure 6: Results screen in URBION tool



4. Results

4.1. Case study

This work focuses on a real project carried out in the Avenida de la Cruz Roja (Seville) to validate the URBION tool. Figure 7 shows its extension, which reaches 500 metres, being divided into 4 segments by transversal streets and maintaining a constant width of 10 metres long. In addition, Figure 8 shows the construction characteristics of the urban elements that establish the initial state of the avenue. The main pavement is asphalt, occupying approximately 3.50 metres in width. A two-way cycle lane, with a width of 1.75 metres, is located on one side of the asphalt. In addition, two pavements are located at either end, each approximately 2.20 metres wide. The avenue is devoid of vegetation and any element that provides shade. The constant traffic of motor vehicles contributes to the increase in anthropogenic generation. These characteristics, together with the warm and temperate climate of Seville, make it necessary to recover the habitability of the avenue and reduce the thermal stress suffered by people in the summer months.

Figure 7: Location

Figure 8: Initial state of the avenue

During the planning stage of the project, the use of the catalogue of components and the calculation tool has been of great help, with the aim of its complete adaptation. For the coverings, those belonging to the textile typology are analysed. The aim is for their transmissivity to be low, with intermediate reflectivity and zero overheating, seeking the integration of new trees to provide shade. Among those tested are textile coverings with 2 and 4% microperforation.

Adaptation on the main living area has focused on eliminating anthropogenic heat and building a pedestrian avenue. The aim is to analyse advanced urban technologies focused on sustainable urban drainage systems. Specifically, 3 different typologies of permeable materials for water harvesting are analysed, making use of infiltration and capture wells to reuse rainwater: porous concrete, stone paving and cobblestones. The albedo of the materials is intermediate and equal to 0.45, so as not to compromise occupant comfort or increase the overheating of the element itself.

By default, low absorptivity pavements and intermediate overheating in the adjacent area are defined. It is considered that the humidity in Seville is low, since in summer periods the average is 20% (Cedar Lake Ventures, n.d.). Given the dimensions of the avenue, a representative area of 12x12 metres is studied, so that the full width of the pedestrian area is considered. Likewise, the metabolic activity of the living area is low as it is intended for resting or moderate activities.

4.2. Evaluating urban adaptation strategies

The URBION calculation engine has allowed a weighting of the urban elements to carry out the adaptation of the avenue. Table 2 shows a summary of the tested coverings and pavements, giving information on their thermal properties. Likewise, each intervention is accompanied by a PET index value, so that the user can analyse the influence of the urban element on the occupant.

Table 3: Initial state of the avenue

Urban element	Tipology	Albedo/Reflectivity	Integrated overheating (ºC)	Integrated PET (ºC)
Solar cover	Microperforation 2% continuous open	0.45	9.10	27.52
Solar cover	Microperforation 4% continuous open	0.45	10.23	30.21
Paving of living area	Thermally activated porous concrete	0.45	5.74	28.10
Paving of living area	Stone paving	0.45	6.91	31.54
Paving of living area	Cobblestones	0.45	8.63	36.83
Paving of living area	Asphalt	0.20	18.00	42,36

The best option to improve the thermal sensation of the person in the avenue is to include 2% micro-perforated, continuous, and open coverings, as well as a porous permeable pavement. These are the ones with the lowest integrated overheating value and PET index. Specifically, the PET values are associated with a slightly warm (yellow) and warm (orange) thermal sensation for the cover and the pavement, respectively. To make an effective comparison of the initial and final state of the adaptation, the analysis of a stay area composed of asphalt and no coverage has been considered. It can be observed that the tool establishes an overheating value of 18ºC, with the PET rising to a value over 40ºC. The improvement offered by the porous concrete on occupant comfort with respect to the initial state of the avenue is 40%.

To further improve the thermal performance of the solutions, it was decided to implement the concept of cold roofing and paving, which make use of rainwater stored in underground tanks to further reduce the surface temperatures of the elements. Likewise, the growth of new trees on the avenue and the recovery of the canopy of the old ones has made it possible to dispense with textile coverings in certain parts of the avenue due to the shade provided by the vegetation. Figure 9 shows the final state of the avenue, showing a clear improvement in habitability and comfort in the central hours of the day.

Figure 9: Later state of the avenue

5. Conclusions

The creation of a catalogue of components and its implementation in calculation methodology has achieved the creation of a new decision-making tool. This tool has been very useful for decision making in a real case, facilitating the evaluation and selection of options more efficiently and accurately. In addition, it has allowed optimizing resources and reducing decision-making time, which has contributed significantly to improving the effectiveness and efficiency in the management of new projects. In future versions, this tool will allow to carry out a thorough sensitivity analysis on the properties of urban elements. This will involve the ability to assess how different variables, such as construction materials, dimensions and location, affect the performance and viability of urban projects. This proactive approach to sensitivity analysis will help anticipate potential challenges and maximize benefits in terms of efficiency, safety and quality of life in urban areas.

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