INTERNATIONAL ASSOCIATION FOR THE STUDY OF TRADITIONAL ENVIRONMENTS

WORKING PAPER SERIES

ENVIRONMENTAL AND CLIMATE-RESPONSIVE URBANISM

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2025
Volume 349

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TRADITIONAL DWELLINGS AND SETTLEMENTS
WORKING PAPER SERIES

Volume 349
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ENVIRONMENTAL AND CLIMATE-RESPONSIVE URBANISM

Traditional Dwellings and Settlements

Working Paper Series

THE EFFECT OF URBAN STREET CANYONS ON THE OUTDOOR MICROCLIMATE IN DENSE MEDITERRANEAN CITIES

Nermine Aly Hany

THE EFFECT OF URBAN STREET CANYONS ON THE OUTDOOR MICROCLIMATE IN DENSE MEDITERRANEAN CITIES

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This paper discusses the impact of urban street canyons on the outdoor thermal comfort of dense Mediterranean cities. Improving the urban microclimate has been an area of extensive research, and urban street canyons remain a huge part of the conversation. The term "urban street canyon" is a phenomenon that is present in dense—often old—Mediterranean cities. It refers to when medium-to-high rise buildings flank a street on both sides, thus creating the feel of a canyon or a tunnel.

Climate change threatens many parts of the world; the Mediterranean region is no exception. Many of the comfortable outdoor spaces may become unwelcoming due to high temperatures and lack of shade during the summer, and high wind and potential flooding during the winter. Not to mention, the already uncomfortable microclimates—most famously created by the UHI effect—could become worse than hostile. Urban street canyons often occur in dense mixed-use residential neighborhoods, where a lot of pedestrian activity occurs. Previous research proved that they can affect the surrounding microclimate, which can play an essential role in optimizing outdoor thermal comfort, even with worsening weather conditions.

This research will focus on the best mitigation strategies with which optimal outdoor comfort can be achieved within urban street canyons. Defined as regional climatic patterns, controlling the microclimate through optimizing the parameters of urban street canyons can reduce pollutant concentration at the pedestrian level, provide optimal outdoor comfort and even mitigate Urban Heat Island [UHI] effects. Such parameters are the urban street canyon's H/W ratio, orientation, and sky view factor (svf). This investigation will be carried out using the ENVI-met model (version 5.0), with which three existing urban street canyons will be modeled. Each will have different H/W ratios and orientations. The simulation runs during the summer solstice, and the results were assessed using the PET index to determine the thermal comfort level of the microclimate created in each canyon. E-W streets proved to be the most unfavorable, even when they have high H/W ratios. However, canyons with medium depth provided comfortable microclimates, while wider ones had less favorable thermal conditions. N-S and NW-SE orientations have proven to be favorable as they provide most shade and are almost parallel to the wind direction, providing a constant air flow.

1. INTRODUCTION

The topic of urban street canyons effecting the outdoor microclimate and comfort has been one in circulation for many years. Oke[1] has been one of the very first to study the topic, focusing on the parameters that optimize the thermal comfort of urban street canyons in mid latitude cities. Additionally, he focused on the geometric features of the canyons, which was a trend that other studies adopted as well. Achour and Kharrat[2] also focused on the geometric feature of urban street canyons in the Mediterranean city of Tunisia that focused on determining the most favorable combination that can produce the best microclimate for pedestrians. Andreou[3] made a study pinpointing the effects of trees in urban street canyons, and its role in creating a comfortable microclimate in canyons where thermal conditions are inheritably unfavorable.

Despite such extensive research in the topic, a gap remains between the research and its application on an urban scale. Another gap represents itself in the form of climate classification; while some studies focus on Mediterranean cities, most pivot on Northern cities where the range of temperatures are significantly lower.

Climate in Southern Mediterranean cities, specifically in the North African region, has been experiencing recurring patterns of heat stress over the past decades. This can be attributed to rapid urbanization and global climate change. The city of Alexandria of Egypt has been one of these cities; and rapid urbanization, loss of vegetation and diminishing green infrastructure has put a tangible stress on pedestrian activity. Moreover, this implores us to reexamine the effect of urban street canyons and how they can help in creating outdoor comfort in a changing and increasingly heated climate.

1.1. Aim and Objectives

The aim of this research is to determine how to optimize the geometric features of an urban street canyon to create the best microclimate on a pedestrian level within it. This will be done through studying the parameters which affect the outdoor comfort the most, as well as analyzing how they interact with one another. Such comparative analysis will help pin down the optimum combination of these parameters and also help suggest design solutions on how to improve the microclimate in combinations that are not favorable.

1.2. Research Methods

Oke[1] considered solar orientation, H/W ratio aspect, and sky view factor as the main parameters affecting microclimate in an urban street canyon, while Tsitoura[4] defined the H/W ratios and orientations of existing street canyons as the "permanent parameters". As this study acknowledges that a street canyon's geometry is a key factor in determining the microclimate it will create—in terms of solar radiation exposure and relation with the prevailing wind—the paper will focus on highlighting favorable and unfavorable conditions created by these each amalgamation of parameters. The paper will utilize deductive, analytical, and experimental methods in order to determine this.

Conclusions drawn from previous research will be put to the test through a 3D simulation model carried out using the ENVI-met model (version 5.0). Three canyons present in the dense city center of the city of Alexandria with various geometric features (H/W aspect ratio, orientation and svf) will be chosen and modeled. The potential temperature and wind speed will be measured at peak heat stress 13pm during the summer solstice sand compared with one another.

2. LITERATURE REVIEW

2.1. Introduction to the morphology of dense Mediterranean cities

It's well known that the spatial patterns of Mediterranean cities are unique in their design. From urban street canyons to dense residential neighborhoods, and open and/or green areas; various variables create different microclimates as such fabrics grow and change.

Understanding and studying the morphology of dense Mediterranean cities is essential for mapping the hotspots of potential discomfort and thermal stress. Therefore, determining these variables through studying the present urban morphology of the city will help draw a map of pedestrian comfort, and then determine how urban street canyons can help improve outdoor thermal comfort.

2.2. Introduction to Mediterranean spatial patterns

The rate of population growth and urbanization in Mediterranean cities are known to be higher than that of regular cities. In fact, population in coastal Mediterranean cities are predicted to increase by 33 million individuals between 2000 and 2025. This is due to constant growth in coastal regions. Dense population tends to create a dense urban fabric, and it includes:

- Urban street canyons
- Dense residential neighborhoods
- Courtyards
- Open and/or green areas

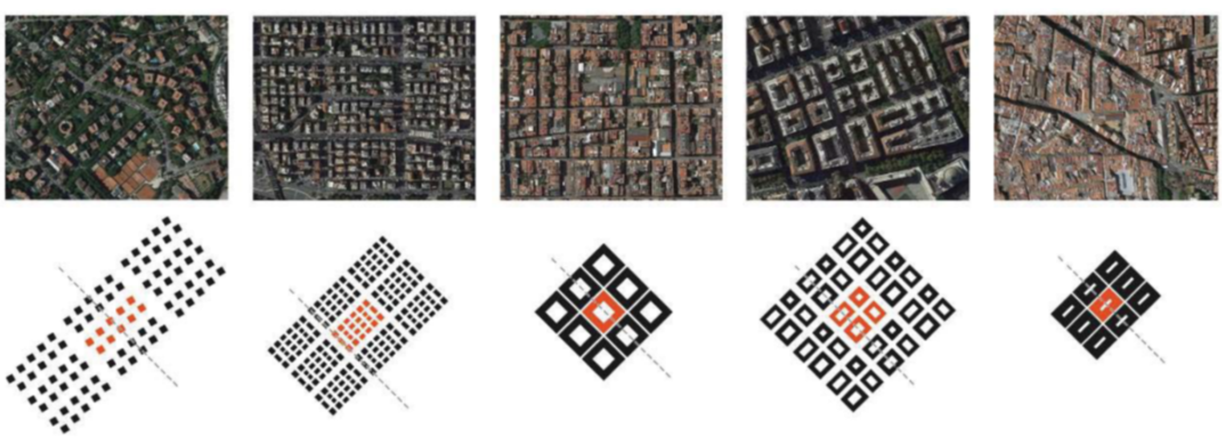


Fig.1. Representing the most common urban fabrics in a Mediterranean city from (S: Based on: Salvati et al., 2015).[5]

Urban street canyons are a result of such compact configuration. Much research has been done on their effect on the urban thermal comfort. T.R. Oke[1] who was one the most prominent researchers on the topic, reflected on the universality of urban street canyons, stating that "Everywhere has streets. Everywhere has buildings."[6]

2.2.1. Introduction to urban street canyons

Urban street canyons are when streets are flanked by buildings on both sides creating a canyon-like space. Streets are generally considered the interface between the architectural and urban scale, as it is the common area between the building and the external environment; they are therefore treated as an individual basic urban unit.[7]

This paper will focus on studying the climate in these canyons present in Mediterranean cities, to extrapolate to such cities as a whole and to explore general guidelines that can help mitigate thermal challenges, such as Urban Heat and possibly climate change.

2.2.2. Thermal comfort in Mediterranean cities

The Mediterranean cities have been showing signs of increasing summer temperatures. This can be greatly contributed to two things: rapid urbanization and climate change.

Fig. 2: Figure represents environmental hotspots on the Mediterranean coast. (S: Based on Mean annual temperature, GRID-Arendal, 2022)[8]

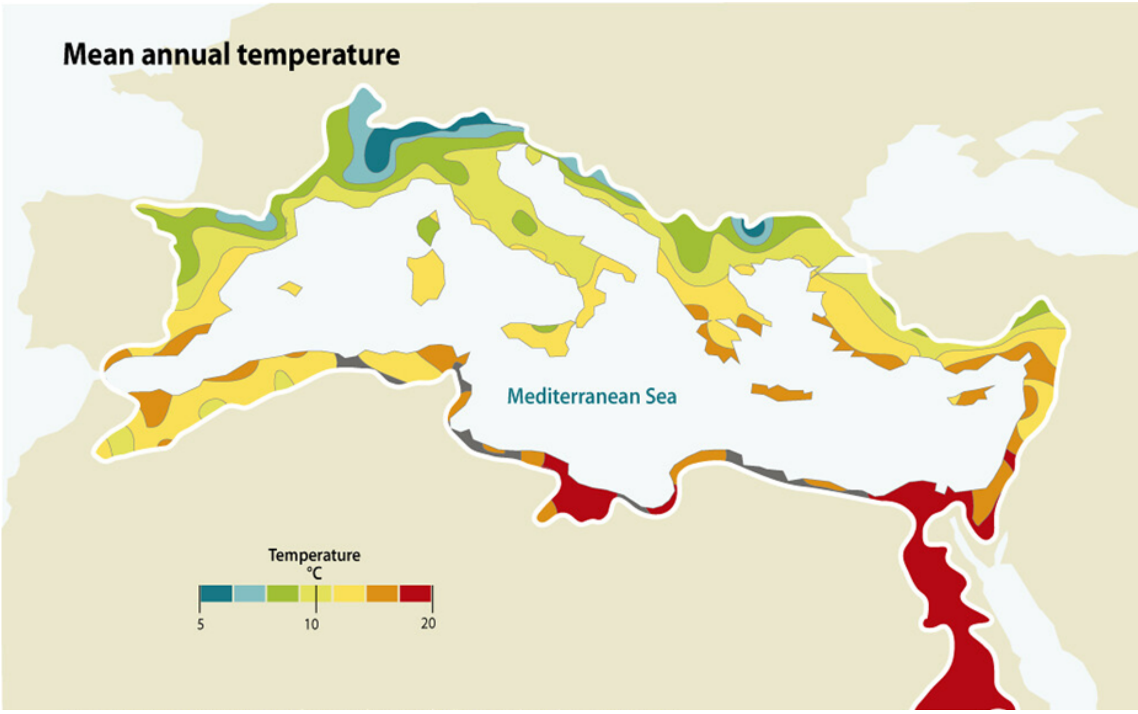


Fig.3: Figure represents the increase in temperature during the past decade. (S: Based on Mean annual temperature, GRID-Arendal, 2022)8

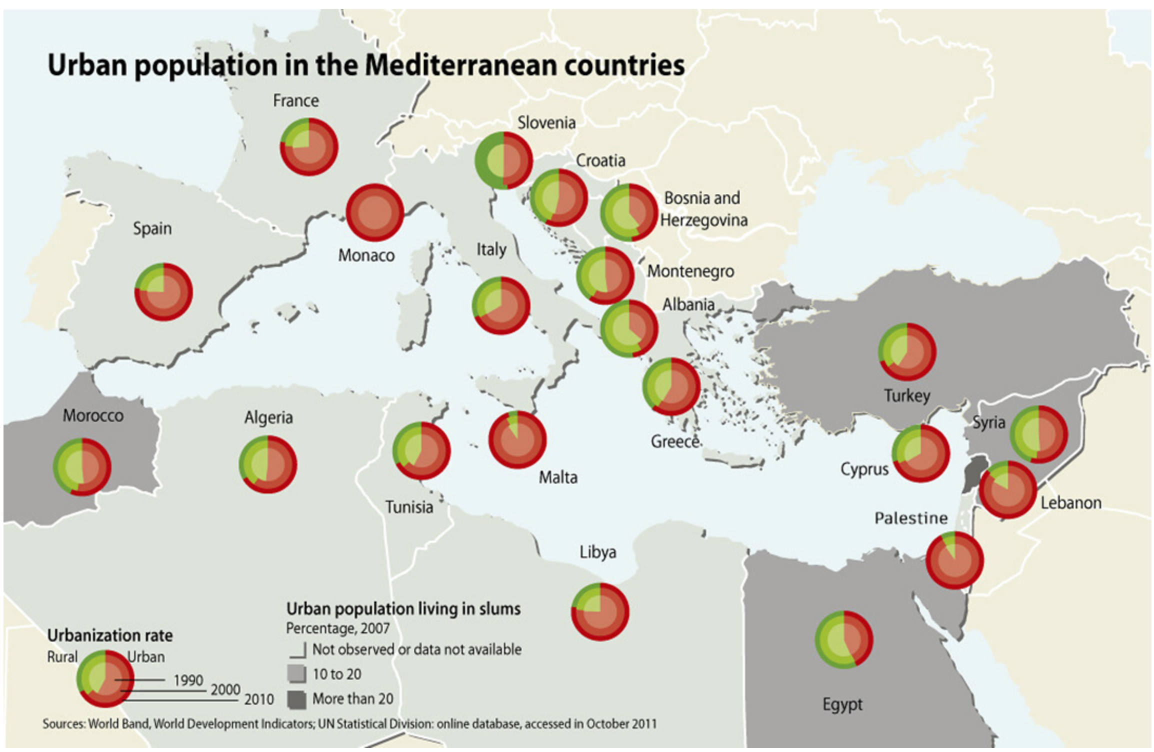


Fig 4. Figure represents the rapid increase in urban population in the Mediterranean region. (S: Urban population in the Mediterranean countries | GRID-Arendal, 2022)[8]

In urban areas, high temperatures generate discomfort outdoor living spaces. This results in a "cause and effect loop", where air conditioning of the interior spaces leads to energy consumptions and anthropogenic heat, which is, in turn, responsible for warming outdoor air. Additionally, the concentration of heat-absorbing materials, heat-generating processes and lack of cooling vegetation contribute to increased temperatures in urban areas, also known as the urban heat island (UHI) effect.[1]

In order to improve the outdoor thermal microclimate, a set of parameters should be considered such as: air temperature, relative humidity, wind velocity, wind direction and storage of solar radiation by the construction materials used. [1,2,10]

2.3. Characteristics of urban street canyons (parameters affecting outdoor thermal comfort)

A study done by Nunez and Oke[1] investigated the energy exchanges in an urban canyon in a typical summer weather. The study showed that the amount of surface energy at various times within the canyon depends on canyon geometry and orientation. Another study done by Andreou[3] proved that the thermal comfort is mainly affected by exposure to solar radiation and therefore, affected by street orientation and h/w ratio. Similarly, another research done by Chatzidimitriou & Yannas [9] identify aspect ratio, sky view, and orientation as the key factors affecting exposure to sun and wind, and thus the formation of different street canyon microclimates.

The consensus is that microclimate in urban street canyons is mainly affected by these parameters:

1. Aspect ratios
2. Orientation
3. Sky view
4. Wind direction and speed

2.3.1. The influence of canyon aspect ratio (H/W)

The aspect ratio is the ratio of the mean height of the buildings to the width of the street. The ratio is especially crucial when it comes to determining the type of airflow in the canyon.[6] The measure of depth of the street canyon is the distance above the canyon itself.

A study done by Chatzidimitriou & Yannas [9] in the Mediterranean city of Thessaloniki, Greece, concludes that wide sheltered canyons (H/W 0.5) as most favorable in winter, except for those perpendicular to prevailing wind, where the deepest canyon (H/W 2.0) is the most comfortable. While in summer, deep canyons seem to be the most efficient in streets with no prevailing wind (for providing shade), while wide and short street are optimum when in the direction of the summer wind.[9]

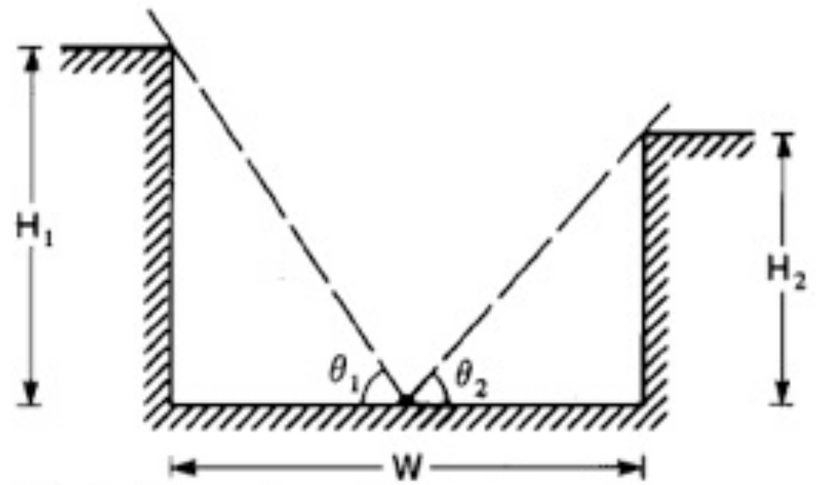


Fig.5: Street Design and Urban Canoby (S: Based on Oke, 1988)[1]

Another study done in city of Tunisia showed that for a Mediterranean subtropical climate, a high ratio H/W could present acceptable conditions of thermal comfort in summer season. The larger the H/W ratio was high, the more comfort it became.[2]

For example, it has been suggested in previous research that increased building height tends to improve air flow rates. This leads to the conclusion that air change rate per hour is directly proportional with building height, the high the buildings the better the movement of the air in between the canyon.

2.3.2. The influence of canyon orientation

The influence of orientation can be summed up in the effect of wind (its speed and direction) and sun path (light and shade). Generally, canyons with north–south orientation were found to be favorable due to amount of shade this specific orientation creates. Present shade reduces the amount of heat materials of pavements and buildings from absorbing, and thus generally producing optimistic grounds for thermal comfort.

In the same study done by Chatzidimitriou & Yannas [9] to determine parameters that create the most favorable microclimate in an urban street canyon in the Mediterranean city of Thessaloniki, Greece, the best results in summer occur in shaded canyons with direction parallel to the prevailing wind. In winter, it is most comfortable in streets exposed to solar radiation and protected from the wind.[9]

2.3.3. Sky view factor

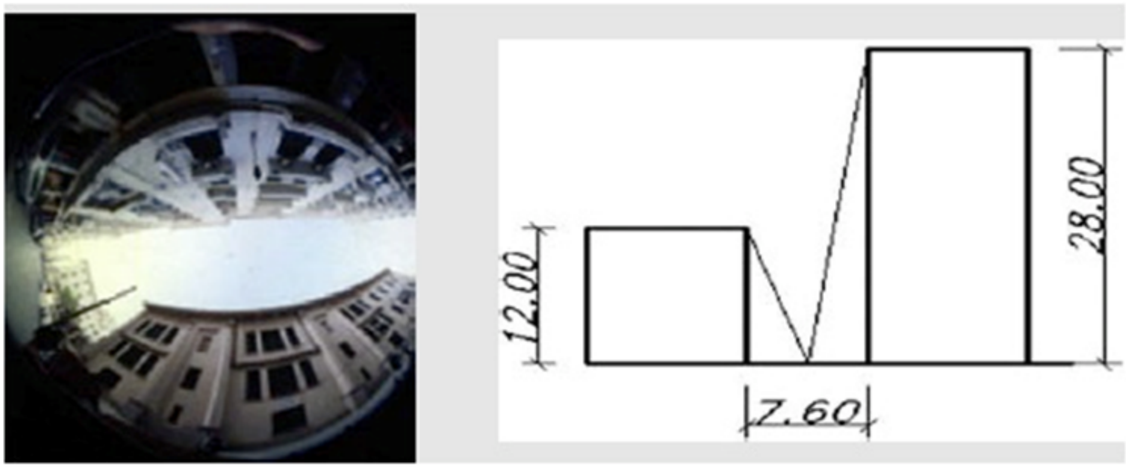


Fig. 6 showing the sky view factor and its impact on the street design (Source: Bourbia, F. "Impact of street design on urban microclimate." Renewable Energy [2009]).[17]

The sky view factor is best visualized through a "fish-eye" photograph of the sky from the street. The value of the sky view factor ranges from zero to one. When obstacles block the sky, the factor goes to zero. When the sky is completely visible, the factor is one. The sky view factor is helpful, for example, in determining the amount of heat a canyon will retain at night. In this case, because the sky is cooler than buildings warmed over the day, the sky can be thought of as a giant heat sink. The more sky exposed, the more quickly the street canyon will cool.[6]

Additionally, it considers the amount of shade present. It also determines the type of air flow that passes through the canyon on a pedestrian level, and on that of buildings. There are three flow regimes: skimming flow (SF), wake interference flow (WIF) and isolated roughness flow (IRF).

In the same study done by Andreou[3], wind speeds were measure in urban street canyons with various sky view factors (svf). The study proved a directly proportional correlation between them; the larger the factor (the closer it is to a "1") the faster the wind speed is.[3]

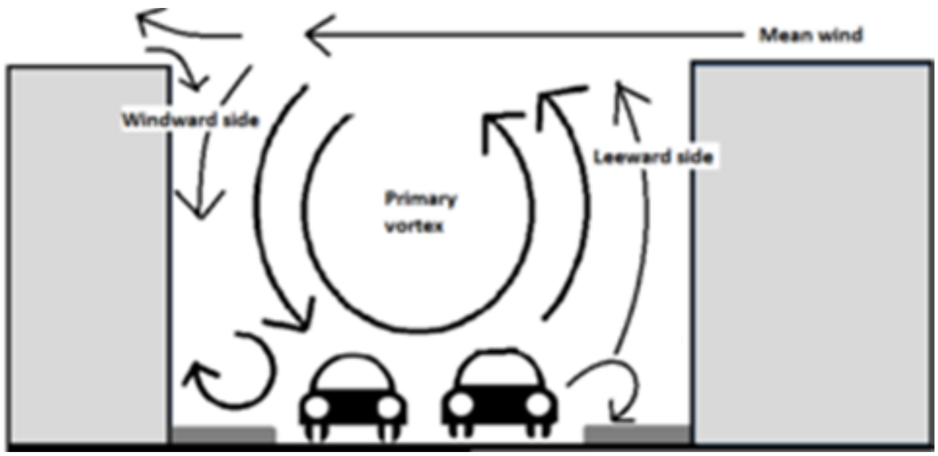


Fig.7: In the skimming flow regime, the wind vortex made inside a street canyon, when wind direction is perpendicular to the street (S: Based on Oke, 1988)[1]

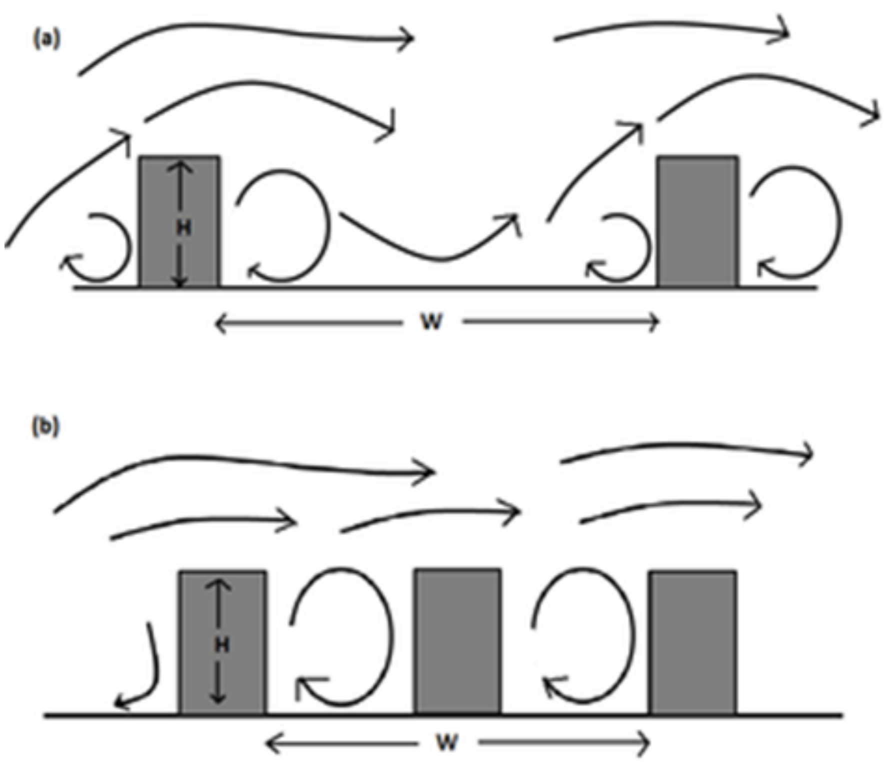


Fig. 8: The comparison of (a) isolated roughness flow and (b) skimming flow regimes in a street canyon (S: Based on Oke, 1988)[1]

2.3.4. Criteria of urban street canyon surface materials

An experiment done by Chatzidimitriou & Yannas [9] examined pavement materials of concrete tiles of similar color and texture and compared it to asphalt in terms of heat retention. At the sites where different pavement materials coexist under comparable conditions, surface temperatures vary up to 4 K. Temperature difference between concrete pavement and asphalt road in summer reached 6 K in NE-SW canyons and 11 K in NW-SE canyons.[9] Higher differences up to 15 K were also observed and were attributed to large variations of solar exposure duration. In winter, with partly cloudy sky, most differences are below 1 K and, in few cases, reach almost 3 K.

2.3.5. The influence of semi-open areas

Many studies have suggested the use of half open space to improve airflow ventilation over urban areas. The integration of semi-open spaces into building configurations could be one of the possible solutions for mitigating the urban heat island (UHI) effect. Although the design of half open spaces in various climate conditions can differ, sufficient natural ventilation conditions within the urban street canyon has been considered an important design factor for more comfortable half open outdoor environments.[11]

2.4. Impact of urban canyon design on outdoor thermal comfort

While thermal comfort relies on both temperate summers and winters, increasingly hot summers are what threatens the quality of the microclimate the most. Consequently, urban street canyons make the most difference and thermal improvements in summer than in winter. Generally, the best results in summer occur in shaded canyons with direction parallel to the prevailing wind and best results in winter occur in streets exposed to solar radiation and protected from the wind.[2,9] This proves that the phenomenon of urban street canyons contributes heavily to the urban heat island effect.

2.5. Challenges facing urban street canyons in improving the microclimate

Architectural, urban design and urban planning interventions should be capable of moderating the outdoor thermal stress by eliminating or reducing extreme conditions.x,[12] However, there still some challenges that need to be put into consideration; vehicular activity is one of them. Such activity doesn't only produce anthropogenic heat but also produces pollutants into the air. This can affect comfort level, on a pedestrian and building level.

2.6. Urban Street canyon strategies that can help improve outdoor climate

The following principles could be used to enhance the outdoor climate in dense Mediterranean cities.

1. Increase H/W ratio
2. Add half open spaces
3. Orientation in direction parallel to prevailing wind
4. Increase sky view factor (svf)
5. Use insulating materials instead of heat retaining ones

As for the geometric properties of urban street canyons that affect its influence the most, it comes down to these three main features: (1) the H/W aspect ratio, (2) the orientation of the street with respect to its geographical location, (3) its sky view factor. These three geometric features will be the centerfold of this paper's analysis.

3. ANALYTICAL EXAMPLES

This study will proceed with analyzing three urban street canyons present in three different Mediterranean cities. The analytical examples were chosen based on several common aspects. Two of the analytical examples were Mediterranean cities, and while the third was not, it was still present in a developing dense city that faces heat stress during the summer and had some meteorological aspects that were present in warm Mediterranean climate such as humidity and high summer temperatures. Additionally, they all had a compact fabric within which urban street canyons existed and suffered from rapid urbanization and outdoor thermal discomfort.

The cities chosen were:

1. Tunisia, Tunisia
2. Camagüeym, Cuba
3. Thessaloniki, Greece

The analysis will compare the average H/W ratio, orientation, and sky view factor of each in a typical summer day, and conclude which combination created the most thermal comfort during the summer months. The canyon aspect ratios have been categorized based on the study done by Andreou [3], where the ratio of building height to street width were ranged as such: 0.4 to 3.3 and were divided into four groups: very wide [0.4–0.7], medium wide [1.0–1.1], medium deep [1.5-2.7] and very deep [2.8–5]. Sky view factor will be categorized customarily, with "0.1" indicating the presence of a lot of obstacles and a difficulty viewing the sky, and "1" indicating the presence of a clear sky view. Orientation will be determined according to the location of each city, and its relationship with the sun path and rest of the parameters accordingly.

These combinations where then analyzed by measuring the air temperature in these urban street canyons and evaluating their comfort level using two indexes: the PET index and UTCI index. This will determine which geometric features in an urban street canyon offer the most favorable thermal outdoor comfort.

3.1. Example 1

Location of street: Tunisia, Tunisia

Streets Description: The urban street canyons studied here are located in one of three different urban fabric present in the city of Tunisia. First is the traditional settlements in the city of Tunisia. The urban fabric containing said street is called "Medina" and is characterized by its dense and compact density. Its streets, narrow and winding, are considered one of the oldest in the city. Close to it is the second type is the colonial urban fabric, characterized by relatively high buildings organized in an orthogonal grid of streets of medium width. Finally, the third type of fabric, the regulated one, is divided into well-regulated residential areas, with detached dwellings along with collective and semi- collective ones. These have the widest set of streets.

Methodology: In this study, the urban street canyons in the three different urban fabrics are analyzed and compared in terms of their H/W aspect ratios, orientations, and sky view factors. The air temperature of each was recorded and expressed in the form of a graph.

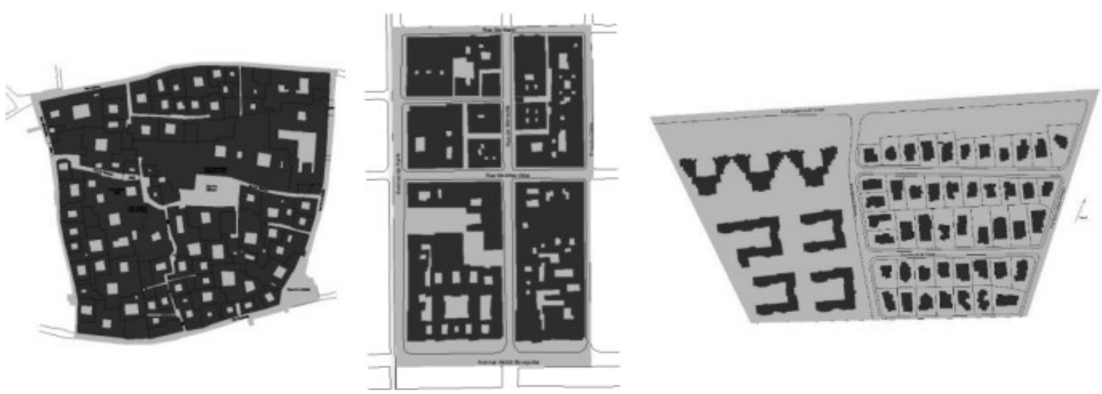


Fig.9: Figure representing the Medina, colonial, regular urban fabric respectively.

The geometric features of each urban street fabric are stated as follows:

1. The urban street canyons of the Medina urban fabric contain the following aspects:
    - H/W aspect ratio: 3.51; very deep
    - Orientation: North-South 247
    - Sky view factor: 0.16

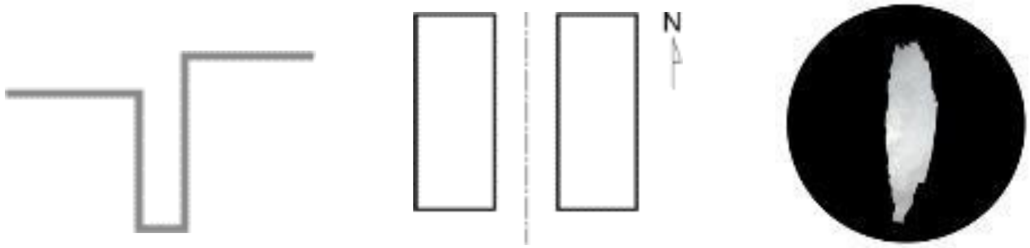


Fig.10: Figure represents the H/W aspects ratio, orientation, sky view factor (respectively) of a typical urban street canyon in the traditional "Medina" residential neighborhood in Tunisia, Tunisia.

2. The urban street canyons of the Colonial urban fabric contain the following aspects:
   - H/W aspect ratio: 1.59; medium deep • Orientation: North-South 254
   - Sky view factor: 0.2

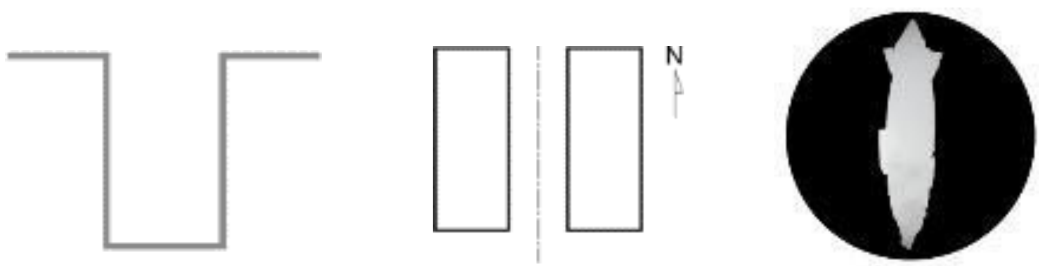


Fig.11: Figure represents the H/W aspects ratio, orientation, sky view factor (respectively) of a typical urban street canyon in the "colonial" residential neighborhood in Tunisia, Tunisia.

3. The urban street canyons of the Regulated urban fabric contain the following aspects:
   - H/W aspect ratio: 0.48; very wide
   - Orientation: Northwest - Southeast
   - Sky view factor: 0.49

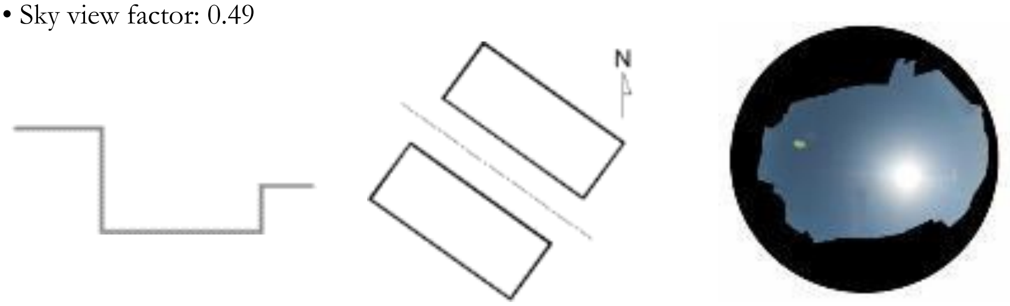


Fig.12: Figure represents the H/W aspects ratio, orientation, sky view factor (respectively) of a typical urban street canyon in the "regulated" residential neighborhood in Tunisia, Tunisia.

Geometrical Features	Example 1: Medina	Example 2: Colonial	Example 3: Regulated
Average H/W aspect ratio	3.51 [Very deep]	1.59 [Medium deep]	0.48 [Very wide]
Orientation	North South	North South	Northwest – Southeast
Average Sky view factor	0.16	0.2	0.49

Table 1: Represent the H/W aspects ratio, orientation, sky view factor (repectively) of the three urban street canyons.

Results and Conclusions: the study concluded that the Medina's North-South urban street canyons with deep H/W aspect ratio and limited SVF are the most comfortable. The urban street canyons present in the wide, clear Regulated fabric of the city were comfortable as well. Both had air temperature of approximately 20 °C, against the colonial fabric's 30 °C.

Wind speed seems to be consistent between the three fabrics, being the highest in the Colonial fabric and least at the Medina's. On the average daily, the fabric of the Medina is located in the area of non-thermal stress with an average of 23.50 °C. It is followed by regulated tissue protruding slightly this area averaging 26.58 °C. Finally, the colonial fabric is one that presents the least good comfort situated in the area of moderate heat stress with an average of 30.06 °C. The fabric of the Medina is the best in terms of outdoor thermal comfort and that the Colonial is the worst.

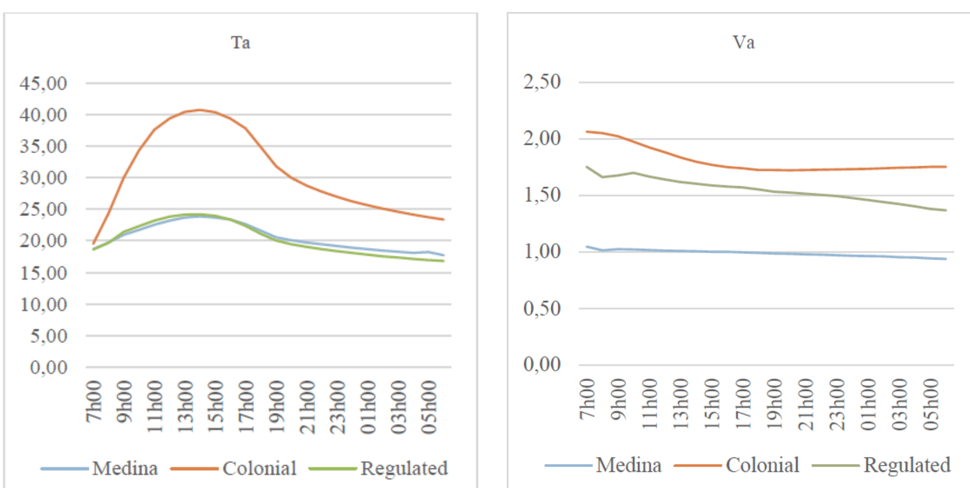


Fig.13: The air temperature [Ta] and wind speed [Va] for urban street canyons in each urban fabric.

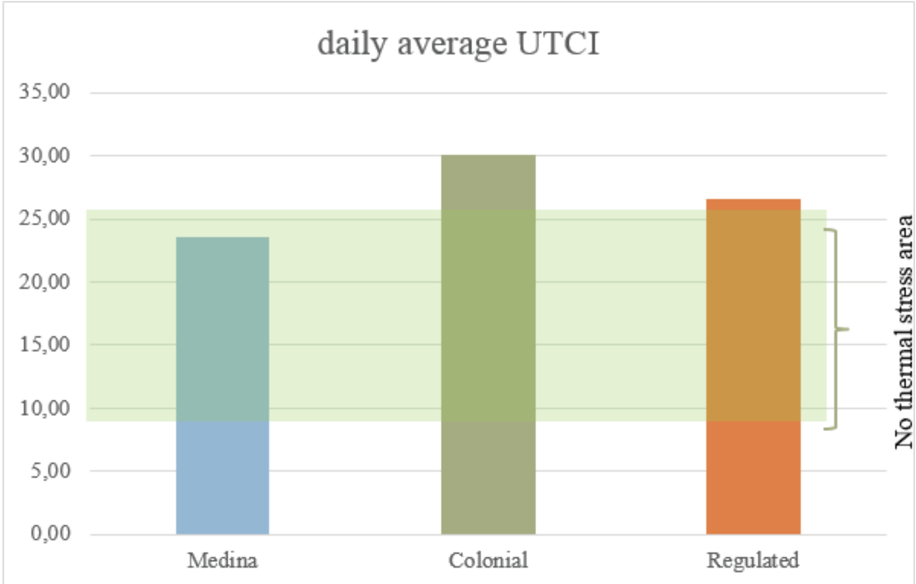


Fig.14: The UTCI values for urban street canyons in each urban fabric.

3.2. Example 2

Location of street: Camagüey, Cuba

Streets Description: The urban street canyons examined here lie in the bustling city of Camagüey, Cuba where its foundational urban core has been inscribed in the World Heritage List by UNESCO since 2008.

Methodology: Simulations of present street canyons were made, with four solar orientations [N-S, NE-SW, E-W, NW- SE] and seven different aspect ratios [H/W= 0.5, 1, 1.5, 2, 3, 4, 5]. Simulations performed are run for the summer solstice. The air temperature of five chronological points marked on the street width [A to E] was measured and the thermal comfort was determined through the PET index.

For the sack of a more legible comparison, three of the most common types of streets will be chosen and analyzed here. The svf was eliminated in the study case, considering the solar orientation and H/W aspect ratios as the main features for being the "permanent parameters" of an urban street canyon.

Geometrical Features: The geometric features of each urban street fabric is stated as follows:

1. The "type 1" urban street canyons contain the following aspects:

• H/W aspect ratio: 0.5; very wide

• Orientation: Northwest – Southeast

• Sky view factor: -

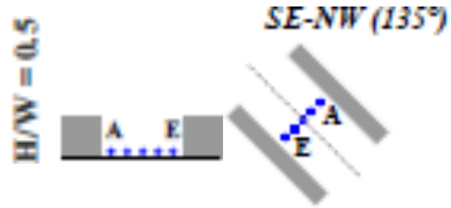


Fig.15: The H/W aspects ratio and orientation of the type 1 urban street canyons in the city of Camagüey, Cuba

2. The “type 2” urban street canyons contain the following aspects:

• H/W aspect ratio: 1.0; medium deep

• Orientation: North– South

• Sky view factor:

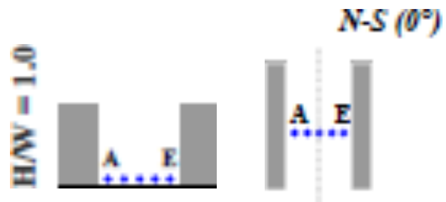


Fig.16: The H/W aspects ratio and orientation of the type 2 urban street canyons in the city of Camagüey, Cuba

3. The “type 3” urban street canyons contain the following aspects:

• H/W aspect ratio: 3.0; very deep

• Orientation: Northwest – Southeast

• Sky view factor:

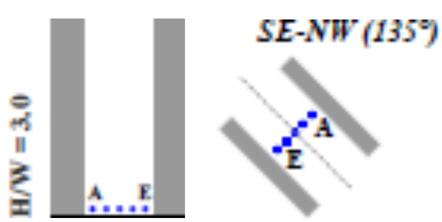


Fig.17: The H/W aspects ratio and orientation of the type 3 urban street canyons in the city of Camagüey, Cuba.

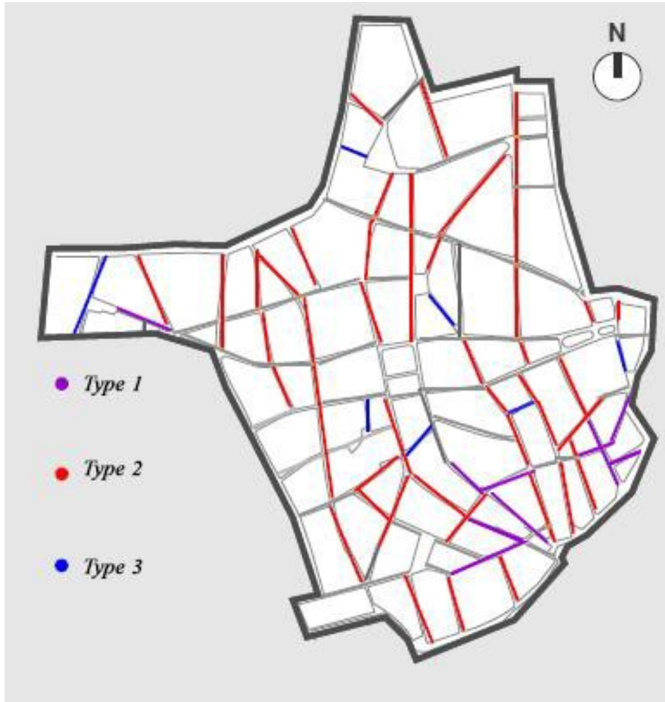


Fig. 18: The types of urban street canyon s in the city of Camagüey, Cuba

Geometrical Features	**Type 1:**	**Type 2:**	**Type 3:**
Average H/W aspect ratio	0.5 [Very wide]	1.0 [Medium deep]	3.0 [Very deep]
Orientation	Northwest – Southeast	North South	Northwest – Southeast
Average Sky view factor	-	-	-

Table 2. represent the H/W aspects ratio, orientation, sky view factor (respectively) of the three urban street canyons.

Results and Conclusions: The results show extreme patterns of thermal comfort between N-S and E-W streets, whereas the N-S provide most thermal comfort in summer, and E-W the most heat stress. Results encourage rotation to N-S orientation as a valid strategy to mitigate the heat stress in summer, with reductions of up to 2 h at the center of the street. Aspect ratios between 1 and 1.5 offer a quite acceptable thermal performance for summer.

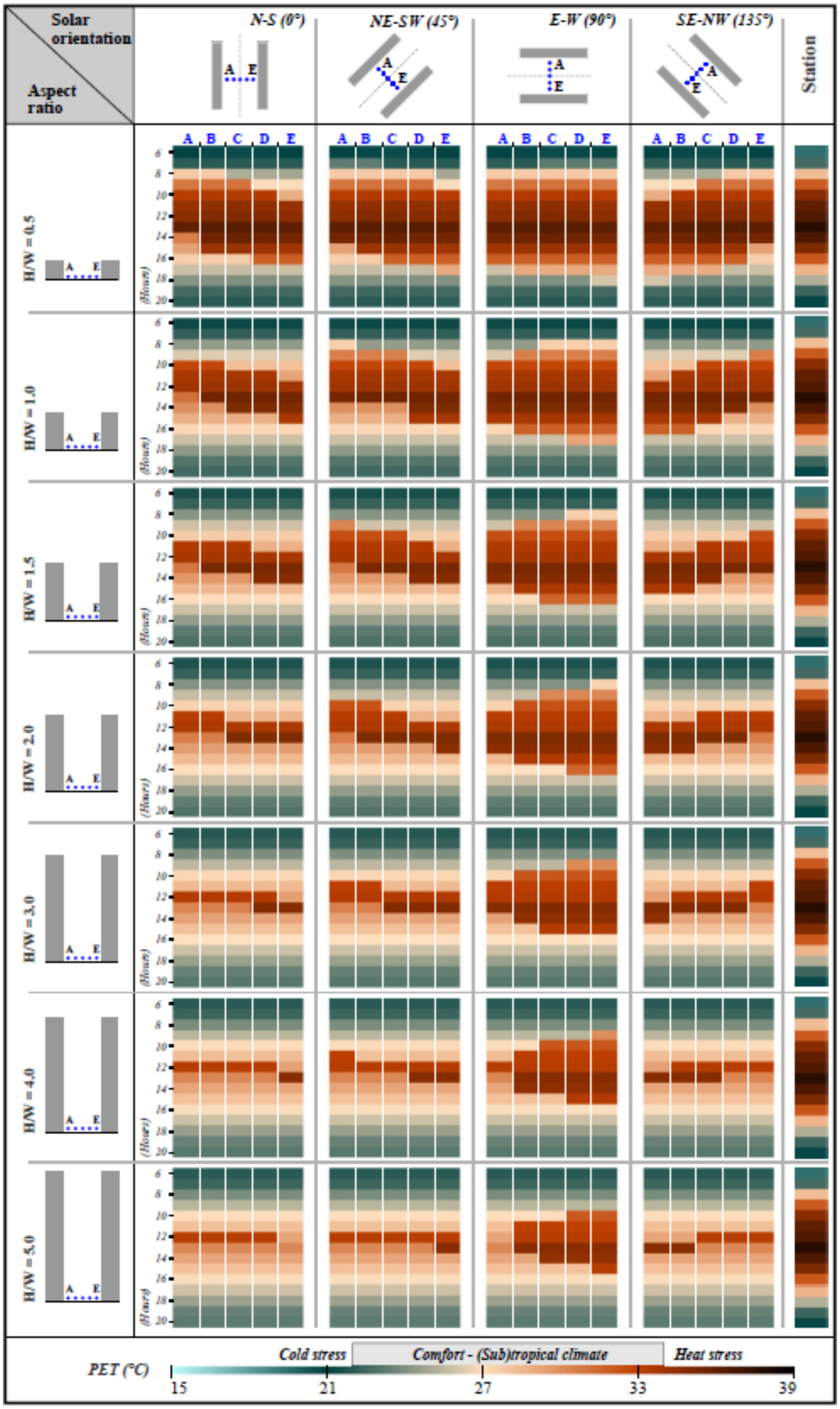


Fig. 19: Figure express the temperatures in a typical summer day and their level of comfort according to the PET index.

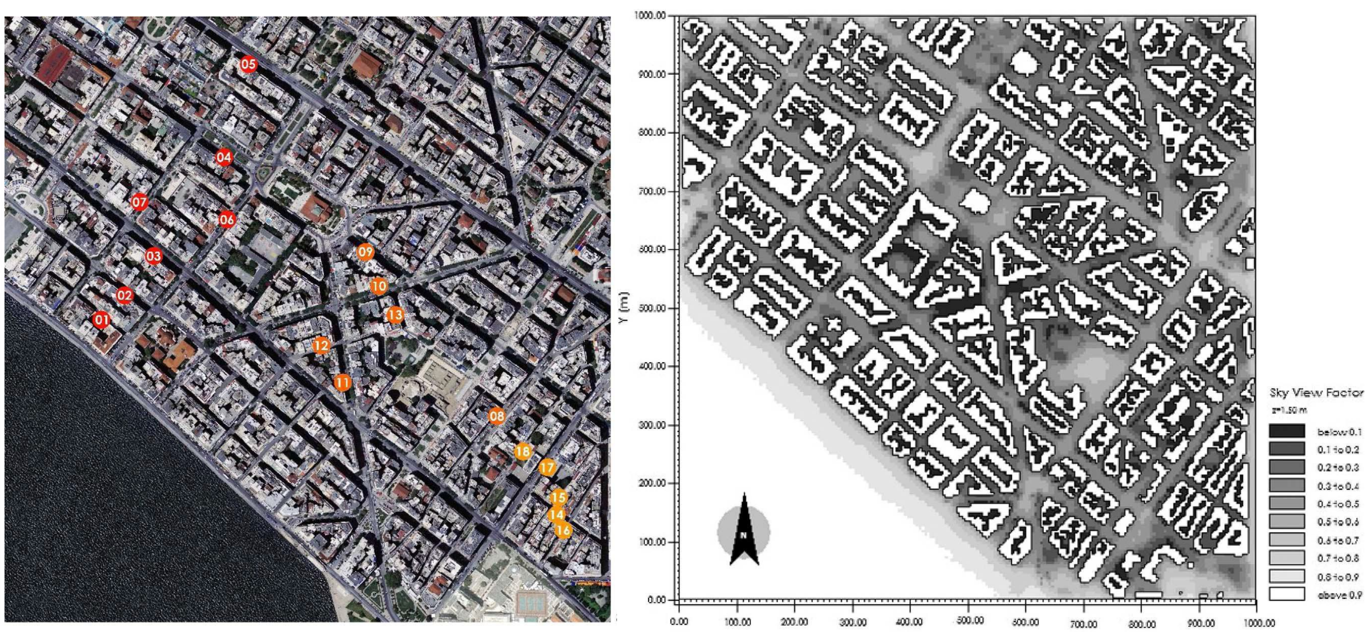
3.3. Example 3

Location of street: Thessaloniki, Greece

Street Description: The urban street canyons of the study is located in the dense city center of the of Thessaloniki, Greece. The climate of Thessaloniki is characterized by very warm and sunny summers and by cold and humid winters. The wind direction in the city of varies from West, Northwest, and South, the prevailing one being the Northwest during the summer months.

Methodology: The H/W aspect ratio, orientation, and svf were calculated for 18 different central streets in the city center of Thessaloniki, Greece. The streets selected for the study included some that had their main axis parallel to the coast and others with their axis perpendicular to the coast and to prevailing winter winds (NW-SE and NE-SW). The investigation also included streets that were diagonal to the normal grid of the city (N-S and E-W). For the sack of a more legible comparison, three of the most common types of streets will be chosen and analyzed here: street 06, street 10, and street 13. This analysis will focus on the results that occurred during the summer months.

Geometrical Features: The geometric features of each urban street fabric are stated as follows:



b

Fig.20: A. Monitoring points in the city center of Thessaloniki (lat. 40.5°N) and B. Sky view factors calculated with ENVI_met.

1. The "street 06" urban street canyons contain the following aspects:

• H/W aspect ratio: 1.0; medium wide

• Orientation: Northeast – Southwest

• Sky view factor: 0.46

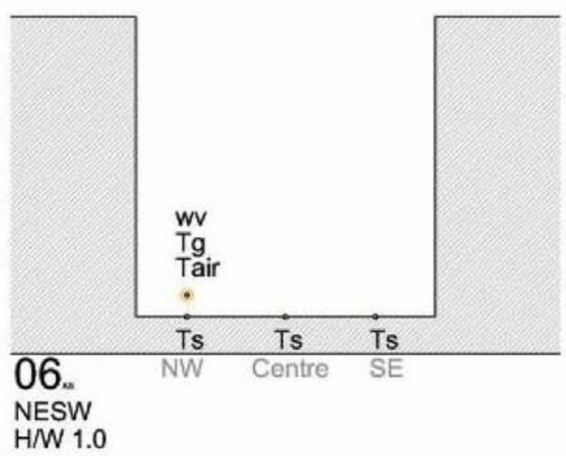


Fig. 21: The H/W aspects ratio and orientation of the type 1 urban street canyons in the city of Thessaloniki.

2. The "street 10" urban street canyons contain the following aspects:

• H/W aspect ratio: 1.7; medium deep

• Orientation: East –West

• Sky view factor: 0.23

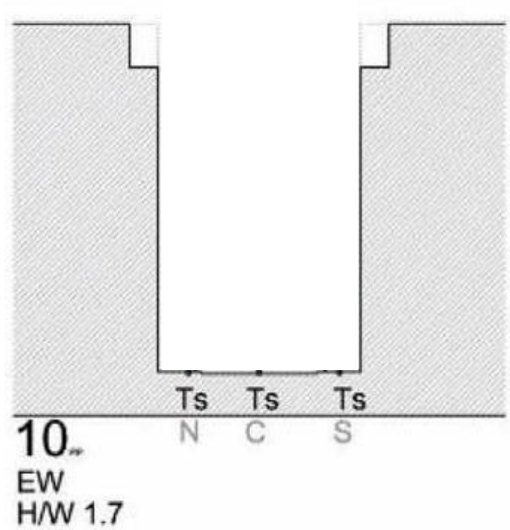


Fig. 22: The H/W aspects ratio and orientation of the type 2 urban street canyons in the city of Thessaloniki.

3. The "street 13" urban street canyons contain the following aspects:

• H/W aspect ratio: 3.0; very wide deep

• Orientation: North–South

• Sky view factor: 0.20

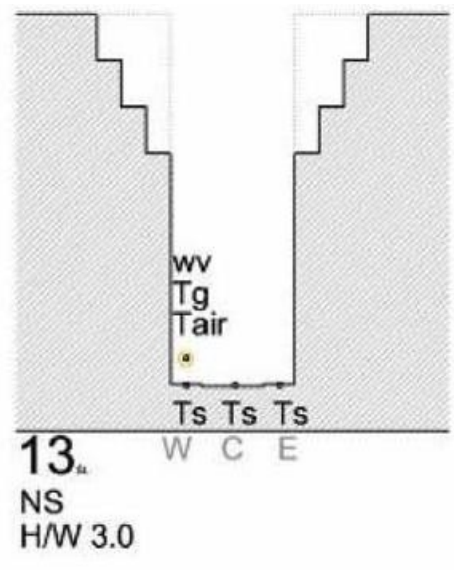


Fig. 23: The H/W aspects ratio and orientation of the type 3 urban street canyons in the city of Thessaloniki

Geometrical Features	Type 1: Street 06	Type 2: Street 10	Type 3: Street 13
Average H/W aspect ratio	1.0 [Medium wide]	1.7 [Medium deep]	3.0 [Very deep]
Orientation	Northeast- Southwest	East-West	North-South
Average Sky view factor	0.46	0.23	0.20

Table 3. Represent the H/W aspects ratio, orientation, sky view factor (respectively) of the three urban street canyons.

Results and Conclusions: In general, comparison among all aspect ratios, indicated as the most favorable axis orientations in summer the N-S and the E-W, with most comfortable conditions at the W and S sides respectively due to shade combined with airflow. In deep canyons, the shaded south side of the E-W canyon appears as most comfortable in summer midday [32.4 °C] and in terms of daily maximum PET values.

The relationship with sky view factors and thermal comfort was most evident with street 10, which had a variation of sky view factors, where areas with lowest value reported the highest thermal comfort and vice versa.

While studying the urban fabric of the city center, courtyard and semi-open spaces provide a thermally comfortable alcove in the urban street fabric.

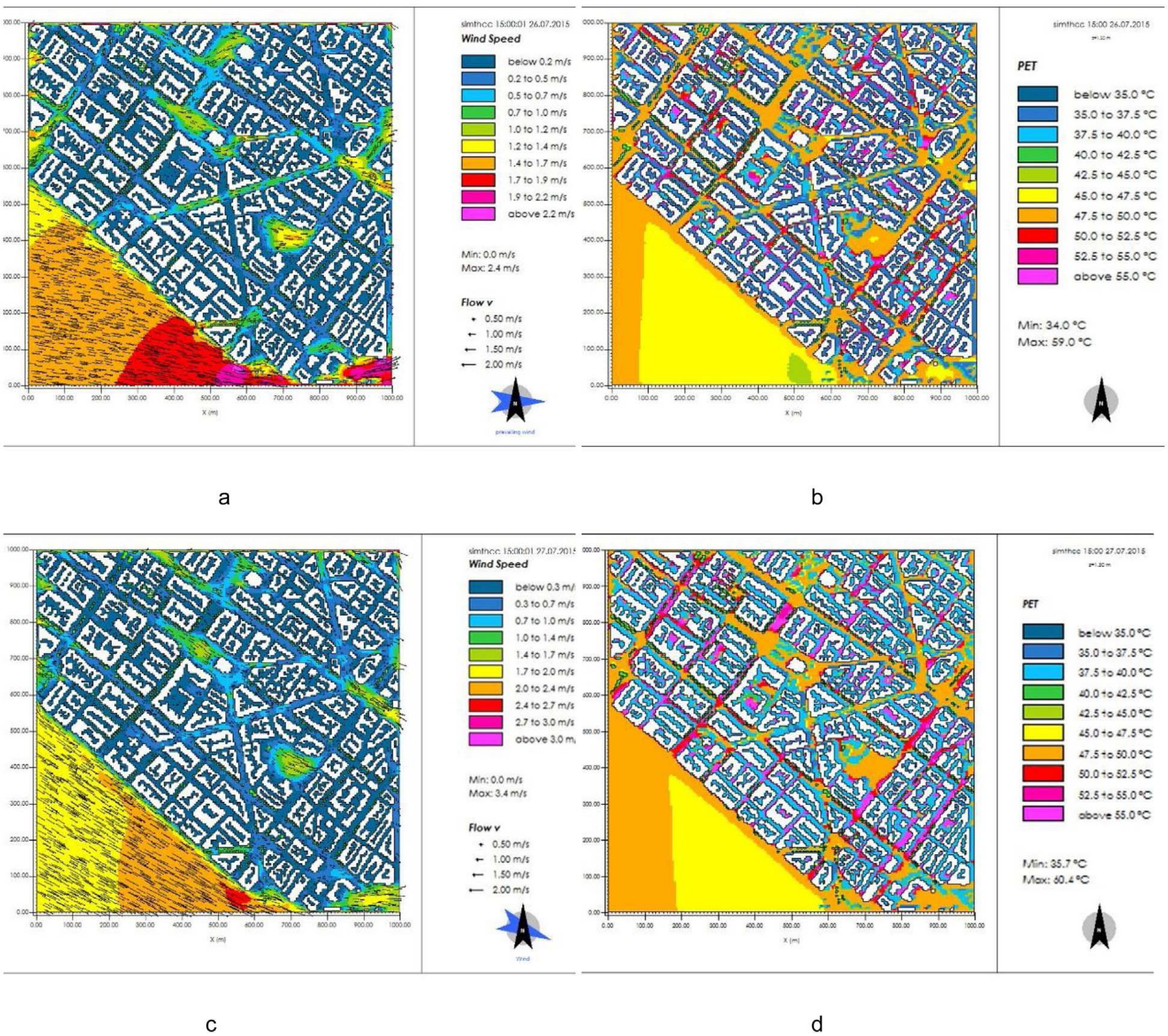


Fig.24: Figure represents the wind speed and PET index [respectively] of the urban street canyons.

3.4. General Conclusion

Thermal comfort has been proved to be dependent on the amount of shade. Consequently, because the combination created by an urban street canyon's H/W ratio, orientation, and sky view factor determine the amount of shade present, thermal comfort is inevitably linked to them. The following conclusions apply in dense cities with typical Mediterranean summers. It has been concluded that:

1. The larger the value of the H/W aspect ratio the more shade is created, and more shade contributes to less heat stress, and thus more thermal comfort.
2. However, in some cases, if the orientation allows too much solar radiation in, sometimes H/W aspect ratios doesn't make much difference, and vice versa.
3. H/W aspect ratios and sky view factors (svf) have a directly proportional relationship.
4. The lesser the value of the svf (less clear sky view), the more temperate and comfortable the air temperature
5. There is a consensus that East-West orientation are the least favorable, while Northern facing urban street canyons are the most favorable.
6. When the prevailing winds are northern, air temperature in urban canyons on the N-S, NW-SE, and NE-SW axis are more favorable compared to E-W canyons.
7. Streets that are perpendicular to the wind direction are least likely to present favorable thermal comfort, while streets that are parallel seem to be favorable.

		EXAMPLE 1 TUNISIA, TUNISIA			**EXAMPLE 2** CAMAGÜEY, CUBA			**EXAMPLE 3** THESSALONIKI, GREECE		
TYPES OF URBAN STREET CANYONS		Type1	Type2	Type3	Type1	Type2	Type3	Type1	Type2	Type3
GEOMETRIC FEATURES	H/W aspect ratio	3.51	1.59	0.48	0.5	1.0	3.0	1.0	1.7	3.0
	Orientation	N-S	N-S	NW-SE	NW-SE	N-S	NW-SE	NE-SW	E-W	N-S
	Sky view factor	0.16	0.20	0.49	-	-	-	0.46	0.23	0.20
UTCI INDEX		24,000	30,000	26,000	-	-	-	-	-	-
PET INDEX (DEGREE CELCIUS)		-	-	-	32.5	27.1	25.1	45.4	47.5	35.5
THERMAL COMFORT		✓	✗	✓	✗	✓	✓	✗	✗	✓

Table 4. Representing the H/W aspects ratio, orientation, sky view factor [respectively] of the three analytical examples and the level of comfort they reached.

4. MATERIALS AND METHODS

4.1. Study area

A thermal comfort analysis was carried out for three different urban street canyons in the city center of the Alexandria, Egypt. Each canyon represents different characteristics in terms of orientation, H/W aspect ratio and sky view factor.

The city center of Alexandria is the city's historic urban center. It was also chosen as this case study for its compact density and vibrant pedestrian activity. Thus, this study proceeds to determine if these three canyons are thermally comfortable on a pedestrian level, and what factors provide the most favorable thermal conditions for future modification and application.

4.1.1. Data

The climate of the city of Alexandria is classified as warm Mediterranean climate, composed of hot summers that last for 4.1 months (from June 8 to October 11), mild wet winters that last 3.2 months (from December 11 to March 18), hu- mid climate, and north-west prevailing winds.[13]According to the Köppen climate index, Alexandria lies in the hot-summer Mediterranean classification.[14]

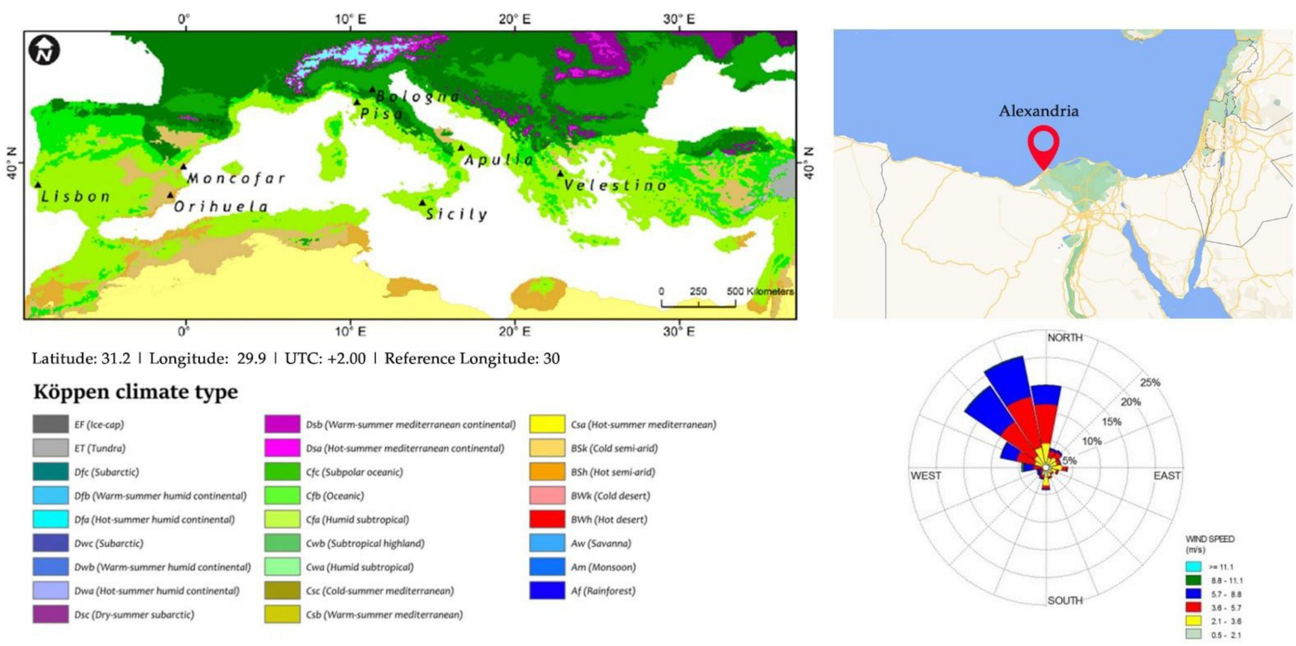


Fig. 25: Location, climatic classification and wind direction of Alexandria, Egypt; map 9S; based on: Pulighe et al., (2018) [15]) and edited by (researcher from Google maps and based on Koppen classification from Melnick et al., (2018))[16].

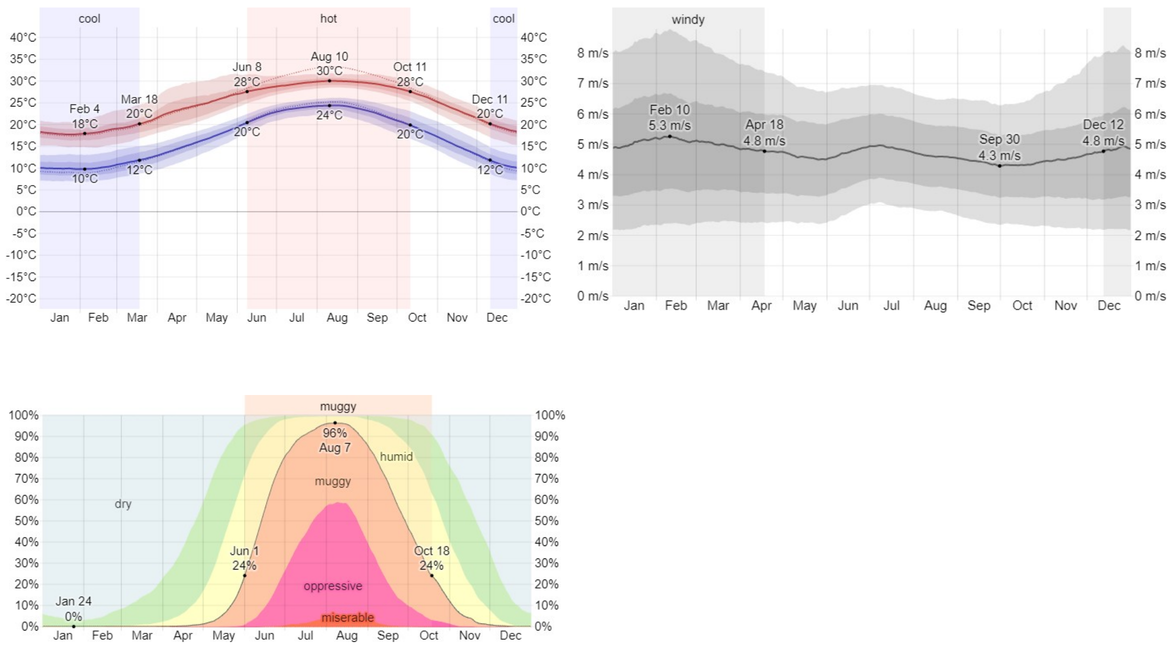


Fig 26: Temperatures, humidity and wind speed respectively [S: Based on Climate and average monthly weather in Alexandria Egypt, 2022].[13]

4.2. Applied Methodology

Since the study aims to predict the effects of different existing urban canyons on microclimate and human thermal comfort conditions, a numerical simulation is the best method for this task. Envi-met (version 5) is used as the simulator in this paper. The conclusions would be drawn from the potential air temperature (°C) calculated for each canyon and then derived from the thermal index that is able to describe and quantify the effects of the thermal environment in human beings. One of the most reliable thermal indexes is the physiological equivalent temperature (PET) index, and it will be used in this study to determine the favorability of each canyon, rating each through two lenses: the thermal perception lens (ranges from very cold to very hot), and grade of physiological stress (ranges from extreme cold stress to extreme heat stress).

As mentioned before, the main parameters used to define the favorability of an urban street canyon are the H/W aspect ratio, the orientation, svf, and wind direction. However, in this study, the svf will be ignored, since it is directly proportional to the H/W aspect ratio and has the same effect on pedestrians. The study will then focus on the H/W aspect ratios and orientations of the canyons, which was categorized by Tsitoura[4] as "permanent parameters".[4]

The study will also focus on the thermal comfort during the summer months; therefore, the simulation will take place during the summer solstice, run for 24 hours and having the results collected and compared at

13:00. The materials used in the simulation were unified in terms of paving (granite paving, asphalt roads) and building façade and insulation. The methodology is planned for the implementation of the results in old cities and the creation of new urban designs.

PET	Thermal perception	Grade of physiological stress
	Very cold	Extreme cold stress
4°C	Cold	Strong cold stress
8°C	Cool	Moderate cold stress
13°C	Slightly cool	Slight cold stress
18°C	Comfortable	No thermal stress
23°C	Slightly warm	Slight heat stress
29°C	Warm	Moderate heat stress
35°C	Hot	Strong heat stress
41°C	Very hot	Extreme heat stress

Table 5. Translating the PET index (S: based on PET index: a revised model for improved thermal comfort | ENS - PARIS-SACLAY, 2022).[17]

Configuration data for the simulation of the three canyons	
Simulation date	21/06/2021
Simulation Time	24h00
Begining of the simulation	06h00
Maxiumum Air Temperature	30 degree Celsius
Minimum Air Temperature	20 degree Celsius
Relative Humidity	16.56
Wind Speed	4.9 m/s
Wind direction	337.5 degree from North

Table 6. Climate simulation configuration settings.

4.2.1. Cases studies and simulation conditions

The three urban street canyons studied in this paper are Foad "El Horeya" street, Nabi Daniel street, and Safia Zaghloul street. Such canyon was chosen for their cultural and historic significance, and consequently, their vibrant pedestrian activity. For instance, Nabi Daniel street's name have not changed in the past 150 years, and several research claim that Foad street dates back to the Hellenistic era of the city.

Just as with the analytical examples, the canyon aspect ratios have been defined based on the study done by Andreou [2013], where they are categorized as such: 0.4 to 3.3 and were divided into four groups: very wide (0.4–0.7), medium wide (1.0–1.1), medium deep (1.5-2.7) and very deep (2.8–5). Moreover, the H/W ratio was determined by creating a ratio between the height average of space (H) and the average width of the street (W).

Fig. 27: Map of the urban street canyons studied from Google maps.

Each canyon has different geometric features; Foad street has the average height of 22m and average width of 12.5m, (H/W=1.76; medium deep) with E-W (247.5°) orientation; Nabi Daniel street has the average height of 9.6m and average width of 8.75m (H/W=1.097; medium wide) with N-S (0° or 180°) orientation; Safia Zaghloul street has the average height of 12m and average width of 15.3m (H/W=0.78; very wide) with NW-SE (225°) orientation.

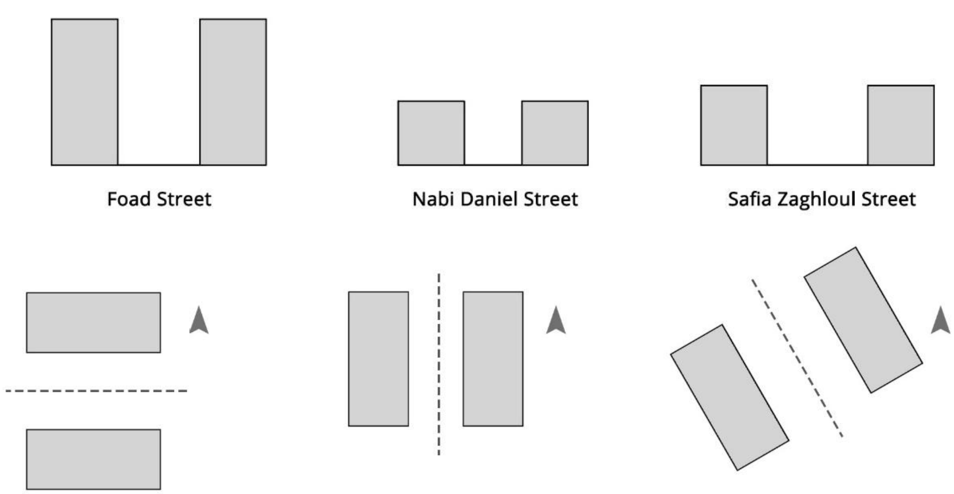


Fig. 28: H/W aspect ratio and orientation of the axes related to the studied canyon.

Urban Street Canyon	Foad Street	Nabi Daniel Street	Safia Zaghloul Street
Length of canyon	50 m	50 m	50 m
Simplified maxiumum height of buildings (m)	22m	9.6m	12m
Size area (cells)	30 x 30 x 30	30 x 30 x 30	30 x 30 x 30
Resolution (m)	2 x 2 x 2	2 x 2 x 2	2 x 2 x 2
Rotation of the model from the North	247.5 degrees	0 degrees	315 degrees

Table 7. Characteristics of the plots to simulate.

5. RESULTS

The results were expressed in several graphic methods. First the air temperature (°C) was taken at peak heat time (13h00) in each canyon and visualized with Envi-met's Leonardo 2D and 3D maps. Then the air temperature (°C) in each hour of each canyon will be presented and compared to the PET index in a line graph. The potential temperature for each of the three streets are as follow:

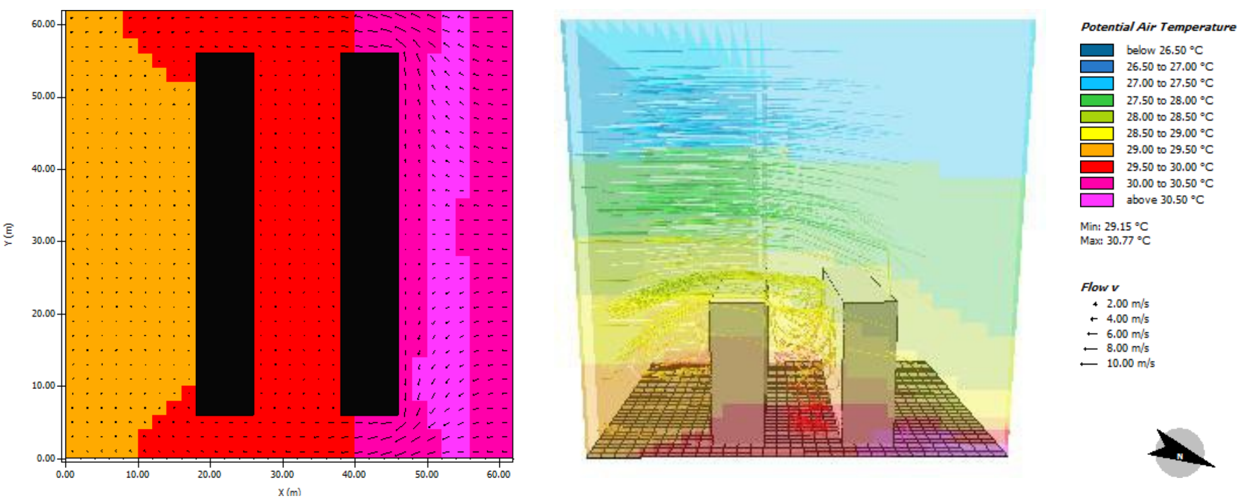


Fig. 29: Foad Street simulation results at 13h00

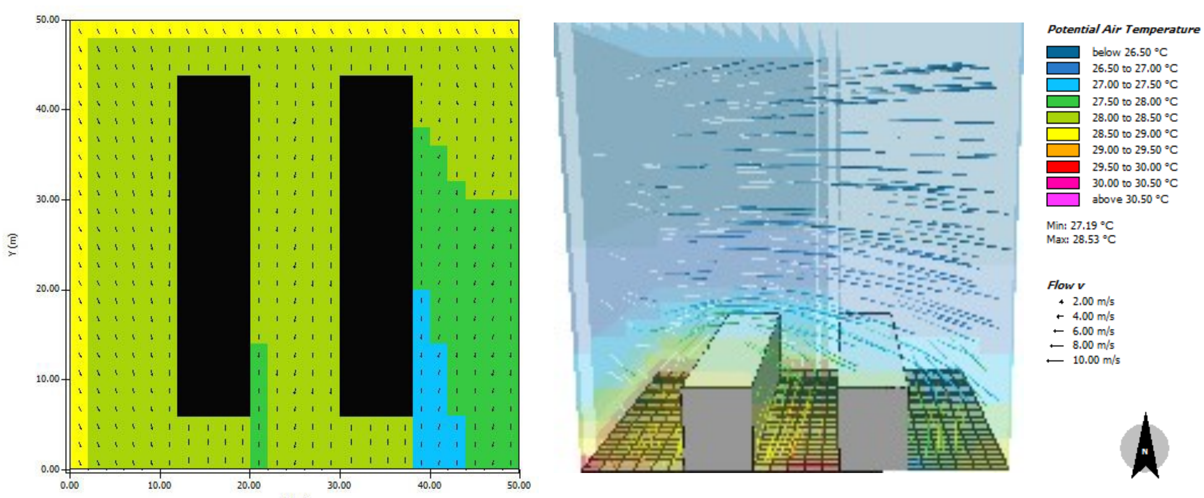
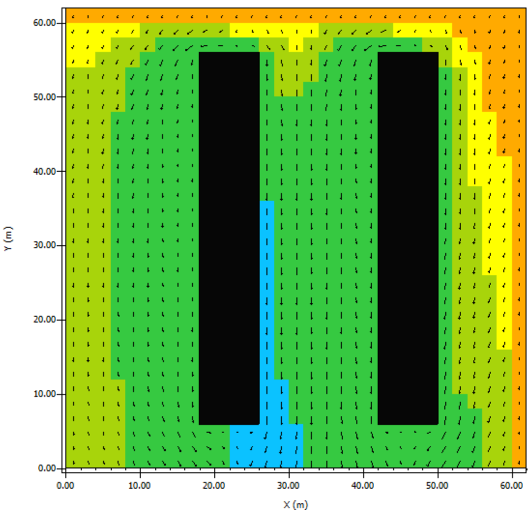


Fig. 30: Nabi Daniel Street simulation results at 13h00



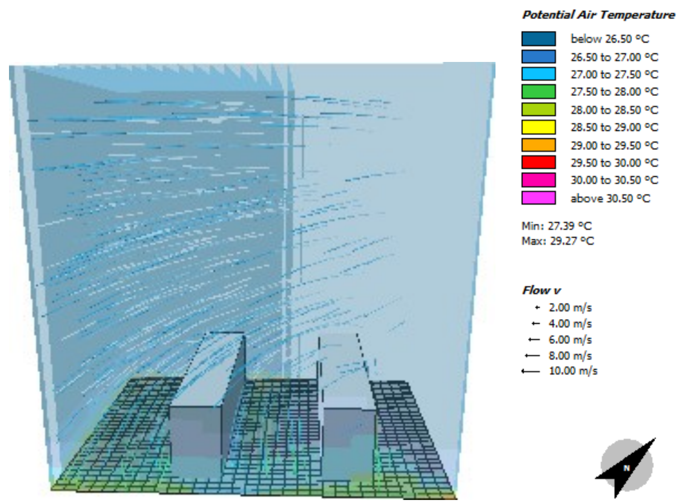


Fig. 31: Safia Zaghloul simulation results at 13h00

5.1. Assessment of outdoor thermal comfort

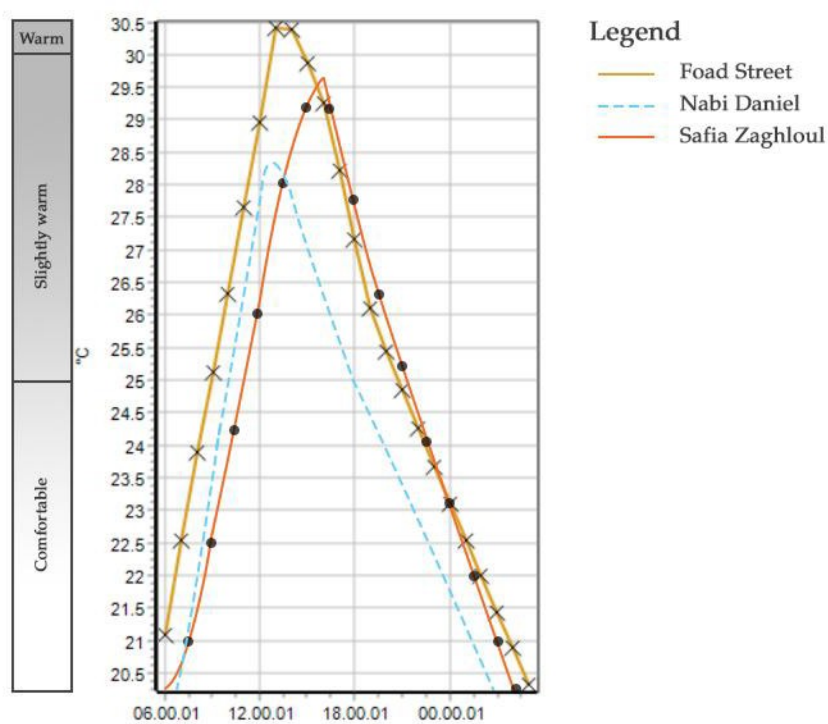


Fig.32: Line graph representing the 24 h 00 potential temperature and PET index of the three canyons.

The best favorable thermal conditions were presented in Nabi Daniel Street, followed by Safia Zaghloul, and finally by Foad Street. Foad street represented the highest heat stress of all urban street canyons, having the highest range of potential temperature, its maximum being 30.77°C. Meanwhile, Safia Zaghloul had the minimum potential temperature of 27.39°C and maximum of 29.27°C. Nabi Daniel, being the most favorable, had minimum potential temperature the 27.19°C and maximum of 28.53°C.

As for wind speed Safia Zaghloul had the highest, with an average of 4 m/s. This is thanks to its NW-SE orientation which was parallel to that of the city's prevailing wind. This was followed by Nabi Daniel [approximately 3.35 m/s] and Foad street [approximately 2.5 m/s].

By studying the results of selected morphological indicators [H/W ratios, wind speed and orientation], a set or urban guideline can be drawn. Wide streets, in this study case represented in Safia Zaghloul street, also represented hours of heat stress, despite having an orientation parallel to the prevailing wind. This proves that wide canyons provide less favorable thermal comfort than deeper ones. However, as shown in the deeper Foad Steeet in Fig.32, the thermal conditions occurring in E-W solar orientation are highly stressful. This is contributed to the E-W sun path being more exposed to solar radiation [twice as many hours] during the summer, as well as— in this case—being leeward due to it being perpendicular to prevailing wind direction. This also reinforces that even though the literature and results concluded that deep canyons [or canyons with high H/W aspect ratio] provide the best outdoor conditions, if the orientation isn't favorable, then the H/W aspect ratio has limited influence and won't be able to significantly improve its thermal comfort.

The most favorable thermal conditions represented themselves in Nabi Daniel Street, with N-S solar orientation, and H/W of 1.097 [medium wide], with the least hours of heat stress during the summer solstice and peak hour of 13h00.

6. CONCLUSIONS AND RECOMMENDATIONS

Both the analytical examples and study case simulations highlight the role the urban street canyon's geometry and position in thermal comfort, as well as their relationship with metrological conditions, namely solar radiation and wind velocity and direction. The best results in summer occur in deep, shaded canyons with orientation parallel to the prevailing wind.

6.1. Conclusions

Simulations and analysis of street canyons in the dense urban center of Alexandria have highlighted that the geometric features of Nabi Daniel Street have resulted in the best thermal comfort between the three. The literature concluded that canyons with depth create favorable conditions, but in some cases where the orientation is E-W, conditions may become uncomfortable due to extensive solar exposure. This is a point that the simulation has proven to be true as results of Foad street has shown. Despite it being the deepest of the three, its E-W orientation put it at a disadvantage and allowed it to be exposed to the sun twice as much as the other two orientations. Meanwhile, Safia Zaghloul street—the widest of the three—has proven to report air temperature higher then Nabi Daniel Street, but still lower than Foad street, proving that wide streets are disadvantageous for achieving a comfortable microclimate but are less harmful than having a E-W orientation—which was another point the literature has stated.

While difference in temperatures in general has been approximately 6°C, its impacts affected the thermal comfort of pedestrians according to the PET index and will probably have larger ones on a bigger urban scale. Therefore, the development of strategies to mitigate thermal discomfort and ameliorating microclimate requires extensive research and data on heat-stressed climatic regions and relating them to the geometric features of the street canyons present in the region's urban fabric. It also requires application on an urban scale to reap the benefits of improved design.

In biology, there is a term called hyper tumor; it is a patch of multiplying cells that results from cancerous tumors and also feeds on them. Such a parallel scene can be drawn upon understanding the benefits of urban street canyons. If cities are organic bodies, urban street canyons are the unplanned urbanization's hyper tumor; a result of a rapid harmful growth that might reduce or control the harmful side effects such growth causes. Additionally, hyper tumor only occurs in big mammals such as whales, just like urban street canyons appear in large cities with exponential growth.

6.2. Limitations

While this paper was dedicated to studying the most comfortable microclimate in summer, it did not consider winter conditions of the Mediterranean climate. It is possible that the geometric feature that are ideal in summer, might not be so in winter. Therefore, this paper might be limiting when considering cold stress and how permanent parameters such as orientation and depth can affect thermal comfort during winter. Based on analyzed literature, the study implores considering tree belts and semi-open space as possible solutions.

6.3. Recommendation

The purpose of this study's results is to create improved guidelines for urban planners, as well as suggestions on how to improve existing canyons. High H/W aspect ratios is favorable, as well as high sky view factors, and so high-rise buildings with correct ratios and ample infrastructure are recommended. While orientation can be a very difficult feature to ameliorate in an existing fabric, it is essential for urban designers to consider it carefully when studying the urban fabric of an extension of a city or when planning a new one. It is recommended for other canyon aspects, such as pavement and building materials and semi-open spaces, to be new pivots for studies concerning urban street canyons.

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RETROFITTING STRATEGIES FOR ENERGY EFFICIENT COMMERCIAL BUILDINGS: PROMOTING COSMOPOLITAN IDENTITY IN DOWNTOWN ALEXANDRIA

Sarah Essam, Mohamed Assem Hanafi, Wessam Abbas

RETROFITTING STRATEGIES FOR ENERGY EFFICIENT COMMERCIAL BUILDINGS: PROMOTING COSMOPOLITAN IDENTITY IN DOWNTOWN ALEXANDRIA

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This research explores the potential of retrofitting to enhance the sustainability and energy performance of commercial buildings in downtown Alexandria. It proposes a holistic framework that aligns with the area's architectural style and cosmopolitan identity while addressing existing challenges. By integrating energy-efficient solutions, the research aims to reduce energy consumption and greenhouse gas emissions, support economic and social vitality, and preserve heritage. The study emphasizes the importance of comprehensive planning and policy development to meet the needs of diverse stakeholders, ultimately revitalizing Alexandria's historic character while achieving modern energy efficiency standards.

1. INTRODUCTION

1.1. Context of the Study

Retrofitting process plays a crucial role in enhancing energy efficiency while preserving the architectural heritage of commercial buildings, particularly in historically significant urban areas such as downtown Alexandria. As a city with a rich cosmopolitan identity reflected in its diverse architectural fabric, Alexandria's commercial buildings often embody historical and cultural value but suffer from outdated construction methods and inefficient energy performance. Many of these structures were built before the adoption of modern sustainability standards, resulting in excessive energy consumption and poor indoor environmental quality (IEQ).

Implementing retrofitting strategies in commercial heritage buildings allows for the integration of contemporary energy-efficient technologies without compromising their historical integrity.
The study of retrofitting in the context of energy efficiency and heritage conservation is particularly important in Alexandria due to the growing pressures of urbanization, climate change, and energy crises. Focusing on this area contributes to sustainable development goals by promoting resource efficiency, reducing carbon emissions, and preserving the city's unique architectural legacy. Furthermore, as global interest in sustainable heritage conservation increases, developing tailored retrofitting strategies for Alexandria's commercial buildings offers valuable insights that can be applied to similar contexts worldwide.

1.2. Aims of the Research

By examining the architectural evolution of downtown Alexandria, this research will propose context-sensitive interventions such as passive design strategies and modern energy-efficient technologies that align with the original aesthetic and structural integrity. It will also address policy frameworks, regulatory challenges, and the best practices according to literature to guide the implementation of effective retrofitting solutions. Additionally, the study can emphasize the broader socio-economic and cultural benefits of preserving Alexandria's diverse architectural identity, reinforcing its role as a living historical and commercial hub while adapting to contemporary sustainability demands. This aim is achieved through a simple structure of four main sectors apart from the introduction and conclusion sections, illustrated in Fig. 1 as follows:

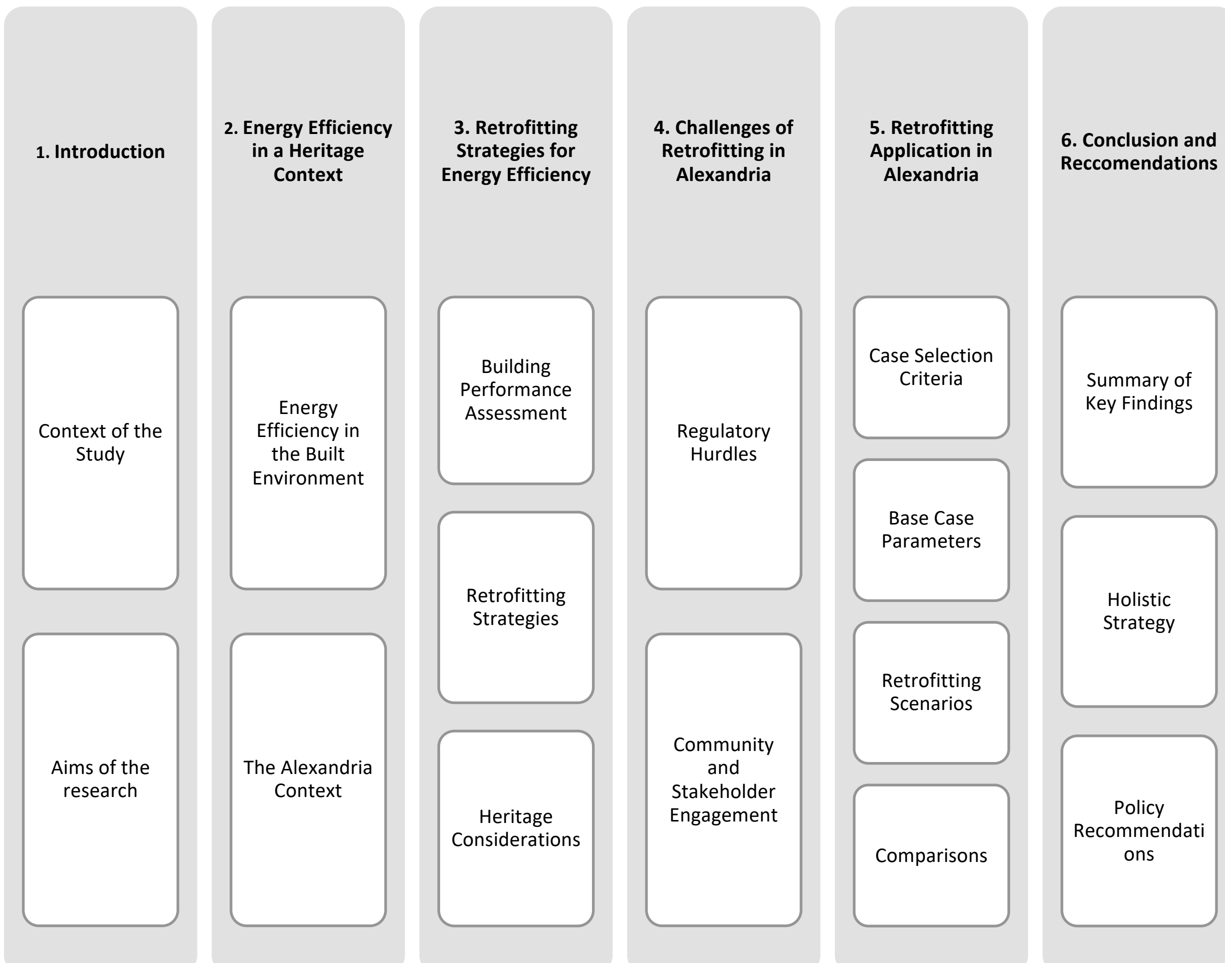

Fig. 1: Research Structure

2. ENERGY EFFICIENCY IN HERITAGE BUILDINGS

2.1. Energy Efficiency in the Built Environment

Energy efficiency in the built environment refers to the optimization of energy consumption in buildings to reduce waste while maintaining or improving occupant comfort and functionality. It involves using advanced technologies, smart design strategies, and operational practices to minimize energy demand and enhance performance. Energy-efficient buildings are designed to consume less energy for heating, cooling, lighting, and ventilation while relying on renewable energy sources whenever possible. According to the United Nations Environment Programme (UNEP), buildings consume about 40% of global energy, 25% of global water, and 60% of global electricity as well as contribute to more than 30% of global greenhouse gas emissions[1]. Improving energy efficiency is a crucial step toward mitigating climate change and reducing dependency on fossil fuels. In commercial buildings, which often have high energy demands due to lighting, HVAC systems, and operational equipment, implementing energy-efficient measures not only lowers costs but also enhances workplace productivity and comfort.

Unlike new constructions designed with energy efficiency in mind, many older buildings were built without modern energy standards, hence contribute significantly to energy waste. Retrofitting involves upgrading various building components to improve performance and reduce overall energy consumption. Additionally, integrating smart building management systems (BMS) and renewable energy sources further enhances efficiency and reduces environmental impact. By prioritizing retrofitting strategies, cities can transform their commercial building stock into more sustainable, cost-effective, and environmentally responsible assets, helping meet global climate targets while preserving urban heritage and functionality.

2.2. The Alexandria Context

Retrofitting commercial buildings in downtown Alexandria presents unique challenges due to the district's blend of modern and historical architecture. One of the primary difficulties is balancing the need for energy efficiency with the preservation of the city's cosmopolitan architectural identity[2]. Many heritage buildings were not designed to accommodate modern energy demands and retrofitting them requires careful interventions that do not compromise their historical integrity. Additionally, financial constraints, lack of clear regulatory frameworks, and resistance from property owners further hinder large-scale retrofitting efforts. The high cost of advanced energy-efficient technologies, combined with limited government incentives, often discourages investment in retrofitting projects. Moreover, the absence of specialized expertise in integrating sustainability solutions within heritage structures complicates implementation.

Despite these challenges, retrofitting presents significant opportunities for enhancing Alexandria's commercial and cultural appeal. By adopting best practices from global retrofitting initiatives, the city can develop tailored solutions that improve building performance while preserving historical aesthetics[3].

Alexandria's rich historical significance presents a unique challenge in balancing heritage conservation with sustainability. As a city that has long been a crossroads of cultures, its commercial buildings reflect a diverse architectural heritage, blending European, Ottoman, and local influences[4]. However, many of these structures were not designed with modern energy efficiency in mind, leading to high energy consumption, thermal discomfort, and maintenance difficulties. Retrofitting these buildings requires a delicate approach that respects their historical identity while integrating contemporary energy-saving solutions. Striking this balance involves navigating strict heritage preservation regulations, ensuring that alterations do not compromise architectural authenticity, and selecting materials and technologies that align with the original design. Additionally, the coastal climate is another layer of complexity, demanding passive cooling strategies and resilient building envelopes. Addressing these challenges calls for innovative, context-sensitive retrofitting strategies that enhance energy performance without diminishing the city's distinctive urban character.

3. RETROFITTING FOR ENERGY EFFICIENCY

3.1. Building Performance Assessment:

Before starting a retrofitting project, the current state of the building and its energy use must be studied and assessed. This initial stage is referred to as an energy audit, it is a systematic process that establishes the base case of the building, recognizing and categorizing energy losses in the building to aid through the decision-making process later[5]. In heritage buildings like those in Downtown Alexandria, energy audits are essential to understand and identify the existing energy-efficient aspects and how they function, as well as to understand and identify its character-defining features to ensure they are preserved.

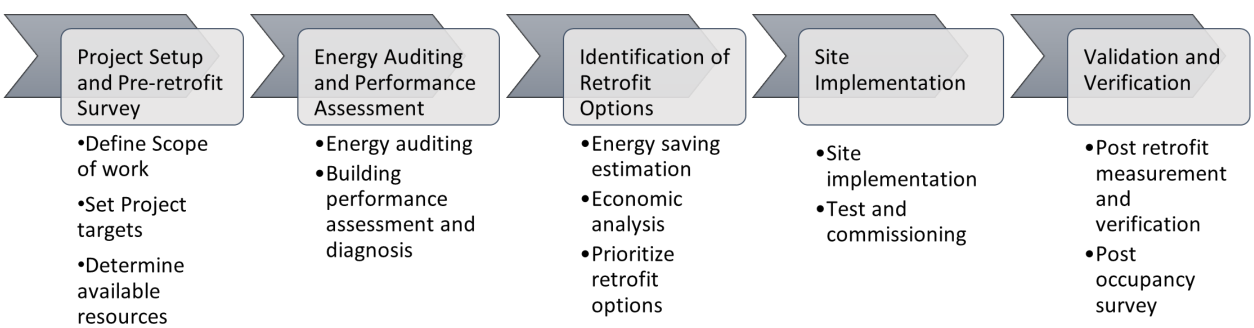

Figure 1: Retrofitting Process Phases[6]

An energy audit usually reveals three performance aspects: areas of energy waste, energy saving opportunities and system operating schedules[7]. Based on the outcome of the energy audit, a suitable retrofitting strategy can be formulated to minimize wastes and maximize efficiency. Table 1 summarizes the most common audit aspects and their impact on energy waste.

ASPECT	PURPOSE	OPPORTUNITIES	CHALLENGES	ESTIMATED ENERGY WASTE
BUILDING ENVELOPE	Detects thermal leaks in walls, roofs, and floors.	Reduces heat loss/gain and improves comfort.	Heritage restrictions require reversible insulation choices.	15-25%
WINDOWS & DOORS	Identifies drafts, glazing inefficiencies, and solar heat gain.	Enhances daylighting minimizing energy loss.	Window replacement is highly restricted.	10-20%
HVAC SYSTEM	Analyzes heating, cooling, and ventilation efficiency.	Identifies inefficient units and suggests replacements.	HVAC changes can be costly and disruptive.	20-30%
LIGHTING	Assesses fixture efficiency and daylight utilization.	Suggests LEDs and motion sensors.	Heritage-compatible lighting is expensive.	5-15%
PLUG LOADS AND APPLIANCES	Measures energy consumption of appliances and office equipment.	Identifies standby power waste and suggests automated controls.	Requires behavioral change from tenants and replacing equipment.	5-10%
RENEWABLE ENERGY FEASIBILITY	Evaluates solar PV potential.	Supports sustainability goals and long-term savings.	Limited roof space and placement restrictions.	10-15%

Table 1: Energy audit aspects, purposes, energy saving opportunities and challenges due to heritage restrictions.

3.2. Retrofitting Strategies

Studies show that different environmental conditions and types of buildings require distinct retrofit strategies to achieve viable environmental, economic, social and technical results. So, it is essential to identify and select which strategies are most appropriate for each situation, considering the local and climate conditions and building characteristics. Knowing the main strategies commonly used in building retrofits, combined with specific methods and criteria, helps in the decision-making process for choosing the ideal set of interventions.

According to Rey[2] there are three main types of strategies, the stabilization strategy (STA), which fundamentally preserves the characteristics and the appearance of the building, the substitution strategy (SUB), which completely changes certain elements and transforms both the characteristics and the appearance of the building; and the double-skin façade strategy (DSF), which partially stabilizes the existing façade and adds a new glass skin. This strategy involves a complete metamorphosis of the building's appearance but maintains a large portion of the original characteristics.

Another method to illustrate retrofitting strategies is active and passive approaches[8]. Active strategies involve upgrading building systems such as HVAC, lighting, and water heating, and incorporating renewable energy sources like photovoltaic panels and geothermal heat pumps. Passive strategies focus on optimizing natural resources, including building envelope insulation, phase change materials, natural lighting, and ventilation.

A different approach to categorize retrofitting strategies divides them into construction and system retrofits, each addressing energy efficiency in heritage buildings. Construction retrofits focus on reducing energy consumption through measures like glazing upgrades, insulation, and enhancing doors and windows[9]. On the other hand, system retrofits aim to optimize natural and mechanical ventilation, upgrade lighting, and incorporate photovoltaic (PV) systems to generate renewable energy, balancing energy efficiency with heritage preservation[10]. This holistic approach ensures heritage buildings remain functional and energy-efficient[11].

The design, materials, type of construction, size, shape, site orientation, surrounding landscape, and climate all play a role in how buildings perform. In order to understand the effect of each of these components, the building is divided into Six Shearing Layers of Change[12]. The development of Brand's Shearing Layers is the Adaptive Future[13] which conducted a set of surrounding layers that explain how a building and its constituent parts will change over time. Combining the work of Austin and Schmidt with existing retrofitting strategies results in the following (Table 2), matching each layer of the building with the possible intervention[14], keeping in mind the need to preserve its historical and cultural value.

Incorporating renewable energy technologies into retrofitting projects can significantly enhance energy efficiency and reduce carbon footprints. Solar panels can be installed on rooftops or facades to harness Alexandria's abundant sunlight, providing clean and renewable electricity[15]. Wind turbines, although less common in urban settings, can be adapted for smaller scales on rooftops or integrated within building designs. Energy storage systems, such as batteries, can store excess energy generated for later use, ensuring consistent power supply[16]. Additionally, integrating photovoltaic glass in windows and facades can generate electricity while maintaining natural lighting. These technologies not only reduce reliance on fossil fuels but also offer long-term cost savings, contributing to the sustainability of retrofitted buildings.

BUILDING LAYER	DESCRIPTION	RETROFITTING STRATEGIES	CONSIDERATIONS FOR HERITAGE BUILDINGS
SITE (URBAN CONTEXT)	The surrounding environment, climate, and infrastructure.	Green roofs or cool pavements for heat reduction. Smart urban shading (trees, pergolas).	Maintain historic streetscape aesthetics Use reversible urban elements.
STRUCTURE (LOAD-BEARING ELEMENTS)	Foundations, columns, and load-bearing walls.	Reinforcement with carbon fiber wraps or steel plates. Seismic retrofitting for structural resilience.	Avoid heavy modifications that compromise historical integrity. Ensure reversible strengthening techniques.
SKIN (BUILDING ENVELOPE)	External walls, windows, doors, and roofs.	Breathable insulation (aerogel, cork panels). Secondary glazing for thermal efficiency. Reflective lime-based coatings to reduce heat absorption.	Maintain façade appearance with non-invasive insulation. Ensure materials allow moisture diffusion to prevent damage.
SERVICES (HVAC, ELECTRICAL, PLUMBING)	Heating, cooling, lighting, and water systems.	Energy-efficient VRF HVAC systems. LED lighting & daylight sensors. Smart water management systems.	Hide modern electrical & HVAC components behind existing architectural features. Avoid invasive modifications to plumbing systems.
SPACE PLAN (INTERIOR LAYOUT & PARTITIONS)	Room organization and furniture arrangements.	Flexible, modular partitioning for future adaptability. Passive cooling & cross-ventilation strategies.	Keep historical interior proportions & decorative elements intact. Use reversible partitions where possible.
STUFF (FURNITURE, FIXTURES, AND EQUIPMENT)	Office furniture, lighting fixtures, bookshelves, etc.	Sustainable furniture choices. Ergonomic, energy-efficient appliances.	Maintain historic aesthetics in furniture choices. Adapt heritage-compatible LED lighting designs.

Table 2: Possible retrofitting strategies based on building layers and heritage considerations.

Another opportunity to consider while retrofitting is Building Management System (BMS), it is an advanced control system that integrates smart technologies like automated controls, sensors, and data analytics to optimize energy use, reduce waste, and enhance building performance[17]. This can be seamlessly integrated and managed using BIM software like Revit, where the focus is on accurate modeling and performance validation before actual system integration. Revit enables designers to create detailed digital twins of buildings, allowing for comprehensive energy simulations and performance analyses during the strategy formulation and pre-retrofitting stage. This facilitates the evaluation of different energy management strategies to optimize building systems and layouts for energy efficiency[18]. BMS also enables predictive maintenance by identifying equipment issues before they escalate, reducing repair costs and downtime[19]In retrofitting projects, integrating BMS can maximize energy efficiency, reduce operational costs, and support sustainability goals by enabling smart energy management and real-time performance monitoring[20]

3.3. Heritage Considerations

Preserving Architectural Integrity

In 2006, Alexandria's authorities enacted Law 144 to protect buildings of significant historical and architectural value[21]. This law led to the listing of 1,135 heritage buildings, imposing restrictions on demolition and modifications that could alter their character[22]. Owners of these properties are required to maintain their structures and seek approval from relevant authorities before undertaking any restoration or renovation efforts. As for energy efficiency specifically, the Egyptian code ECP 306-2005 provides guidelines for any additions or modifications to existing commercial buildings [23], whilst respecting the cultural and heritage value and the requirements of Law 144.

Sustainable Building Materials

Retrofitting heritage buildings using sustainable, local materials can significantly enhance energy efficiency and indoor air quality while preserving cultural identity. The regulations of the Supreme Council of Antiquities strictly regulate modifications, requiring the use of compatible materials and techniques to maintain building authenticity[24]. For instance, materials like natural stone, terracotta, and lime-based mortars are breathable and moisture-regulating, reducing the need for mechanical ventilation and improving thermal performance[25]. Additionally, using locally sourced, low-emission materials minimizes transportation emissions and supports the local economy. Such practices align with adaptive reuse strategies that prioritize sustainability without compromising heritage value.

4. CHALLENGES OF RETROFITTING IN ALEXANDRIA

Retrofitting commercial buildings in cosmopolitan downtown Alexandria requires careful navigation of local building codes, zoning laws, and heritage preservation regulations to ensure both compliance and the safeguarding of the area's architectural legacy. It also needs to consider the financial barriers and stakeholder’s resistance to nonsubsidised retrofitting projects.

4.1. Regulatory Hurdles

The existing legal framework lacks clarity and enforcement mechanisms, making it difficult to implement preservation laws effectively. Specific interior codes for the adaptive reuse and rehabilitation of heritage structures are absent, and only general building regulations apply[26]. These regulations do not account for the unique needs of historic buildings, leading to challenges in integrating modern amenities without compromising structural integrity, and inconsistent application of preservation principles.

4.2. Community and Stakeholder Engagement

Property owners may resist retrofitting due to the high cost, particularly when using specialized materials and skilled labor to preserve the historic character. Many owners lack financial incentives or subsidies to justify the investment, especially if rent control or zoning laws limit potential revenue gains. Moreover, obtaining approvals from heritage conservation authorities can be time-consuming and restrictive, discouraging owners from undertaking upgrades[27]. Some may perceive regulations as too rigid, preventing practical improvements such as modern insulation, window replacements, or HVAC upgrades. Some owners worry that major renovations might reduce the building's heritage authenticity, affecting its perceived value. Others fear gentrification, where increased property values lead to higher taxes or pressure to sell.

Businesses operating in heritage buildings, such as bookstores, cafés, and offices, may resist retrofitting due to noise, dust, and temporary closures[28]. Disruptions to work schedules and productivity losses can be a major issue. If landlords pass retrofitting costs onto tenants, rental rates could increase, making it harder for small businesses to stay. Upgraded energy systems might reduce utility bills, but some tenants may not perceive the long-term benefits as outweighing immediate cost increases.

Some stakeholders may resist changes due to a belief that modern energy-efficiency upgrades will compromise authenticity. Lack of awareness about heritage-friendly retrofitting solutions (e.g., reversible insulation techniques) could contribute to resistance. Addressing these challenges necessitates a holistic balanced approach that harmonizes development goals with the imperative of conserving Alexandria's rich architectural heritage. Figure 2 illustrates the different factors affecting the retrofitting process.

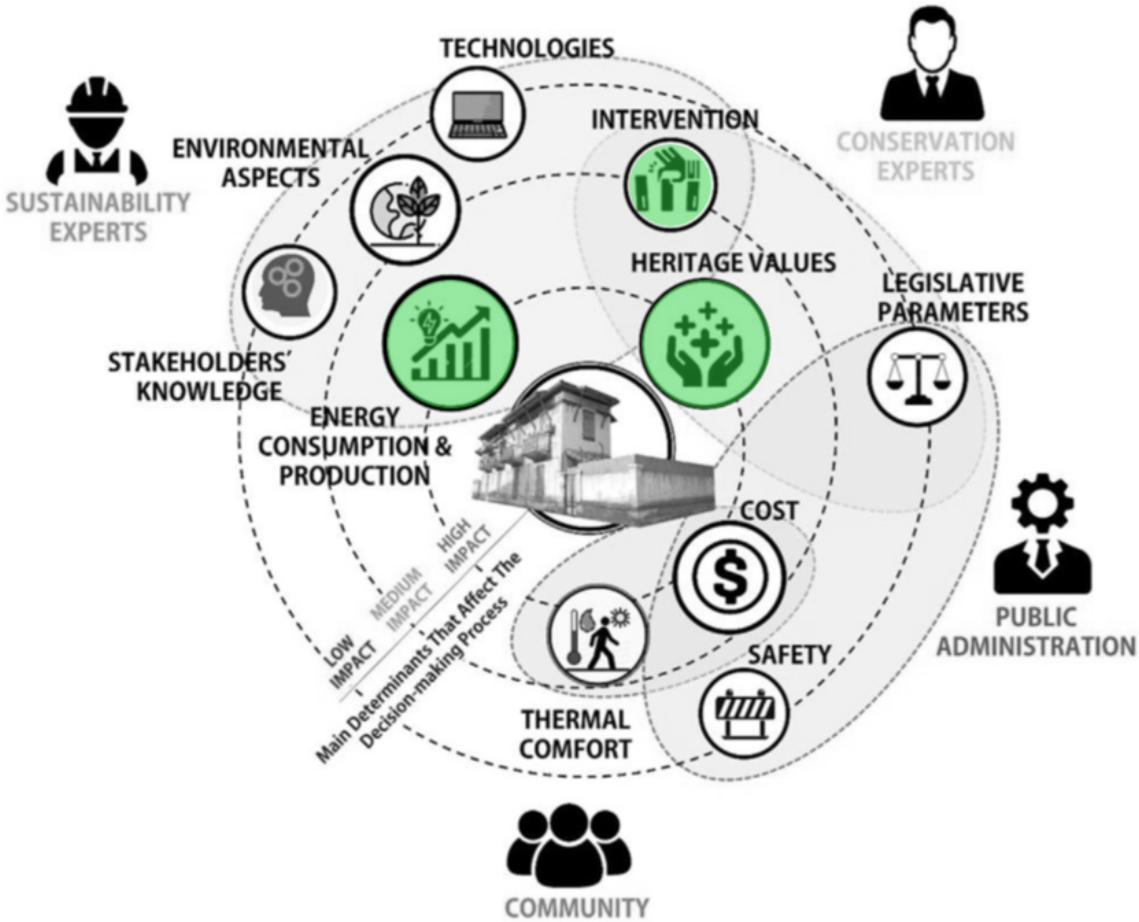

Figure 2: The main aspects that affect the retrofitting decision process[29].

5. APPLYING RETROFITTING IN ALEXANDRIA

5.1. Building Description and selection criteria

The Palazzina Aghion, designed by Italian architect Antonio Lasciac in 1885, is a significant representation of Alexandria's Italian architectural influence during the late 19th century. Commissioned by the Aghion family, the building reflects a blend of neoclassical and eclectic styles, characteristic of Alexandria's cosmopolitan heritage at the time.[30]

Today, it is known as Al Ahram Building, and the ground floor houses Al Ahram bookstore, while the upper three floors serve as administrative offices (Fig. 3). This adaptive reuse has ensured that the building remains an active part of Alexandria's urban fabric, continuing to serve commercial and professional functions without losing its historical identity, especially after the urban regeneration initiatives along Nabi Daniel Street and Fouad Street, which played a crucial role in maintaining Alexandria's historic core. These projects aim to enhance pedestrian accessibility, restore heritage buildings, and revitalize cultural and economic activity. However, while these efforts have helped preserve the district's character, they have also introduced challenges, such as increased commercial pressure and the need for updated infrastructure to accommodate modern demands.

Figure 3: Before and After Photos of Al Ahram Building, previously known as Palazzina Aghion[31]

The building consists of 4 floors, each of an area about 270 m^2 , the total area is about 1000 m^2 and the ceiling height in the ground floor and mezzanine is 6 m, while in the typical floor it is 4.75 m. The exterior walls are made of terracotta bricks with no extra insulation, and the all the windows are wooden casement windows with a wooden shutter and single glass glazing. The northern façade has no shading while the southern façade has recessed openings and balconies acting as shading devices. The HVAC units are all split of an old model, and the lighting system is manually controlled hybrid between LEDs and fluorescent bulbs. Based on the occupancy patterns and activities, the total energy consumption is around 100,000 kWh/year.

When applying the energy audit based on the layers of the proposed strategy, the following energy wastes are detected (Table 3). Dividing the wastes according to the layers facilitate specific strategy proposals that target the problem areas and improve efficiency.

ASPECT	ISSUE IN AL AHRAM BUILDING	ESTIMATED ENERGY WASTE (%)
BUILDING ENVELOPE (INSULATION & AIR LEAKAGE)	Terracotta bricks have poor insulation, leading to high heat gain/loss. No added insulation.	25-30%
WINDOWS & DOORS	Single-glazed wooden windows allow significant air leakage & solar heat gain.	20-25%
HVAC SYSTEM	Old split units likely oversized or inefficient, struggling with high heat loads.	15-20%
LIGHTING	Fluorescent and LED mix; daylighting is underutilized in some office spaces.	5-10%
PLUG LOADS & APPLIANCES	Laptops, PCs, printers, and standby loads contribute to phantom energy use.	5-8%
RENEWABLE ENERGY FEASIBILITY	No solar integration despite ample rooftop space.	10-15% (potential savings missed)

Table 3: Al Ahram building energy audit outcome

5.2. Retrofitting Scenarios

In response to the audit findings, and based on the strategies mentioned earlier, and Alexandria's Mediterranean climate, three retrofitting scenarios accounting for seasonal variations are derived to optimize thermal comfort and energy efficiency. Each scenario focuses on season-specific challenges while preserving the building's heritage value and aligning with EPC 306-2005 recommendations.

The first scenario (Table 4) is targeted to optimize building performance during summer, to reduce cooling loads and prevent overheating. Based on Alexandria's climate profile, summer weather is hot and humid, with temperatures varying between 26°C to 32°C and humidity often exceeds 70% with strong solar radiation.

BUILDING LAYER	PROPOSED RETROFITTING MEASURES	ENERGY IMPACT
SKIN	Apply reflective lime-based coatings on the roof to reduce heat absorption. Use secondary glazing with UV-filtering films to minimize heat entry while preserving window aesthetics.	15-25% reduction in cooling loads.
SERVICES (HVAC-ELECTRICAL)	Install VRF air conditioning system with smart zoning controls. Optimize ventilation strategies (encouraging cool night air circulation). Use motion sensors for lighting & AC automation in unoccupied rooms.	30-40% reduction in electricity usage during peak summer months.
URBAN CONTEXT & LANDSCAPE	Apply cool pavement materials in surrounding areas. Introduce vegetation on roof to decrease heat gain.	5-10% reduction in localized heat buildup.

Table 4: Summer retrofitting strategy

The second scenario is concerned with reducing mild heat loss and enhancing passive comfort during winter, the main goal is to achieve thermal comfort during winter without active heating systems. As winter is mild and rainy, with temperatures ranging between 10°C to 18°C, and frequent rainfall and coastal winds. The main issue during winter is moisture control to minimize salt damage is Al Ahram building. It utilizes passive measures and draft reducers.

BUILDING LAYER	PROPOSED RETROFITTING MEASURES	ENERGY IMPACT
SKIN (ENVELOPE)	Apply thermal curtains or interior secondary glazing to reduce drafts. Seal air leaks using reversible caulking and draft excluders. Use thermal shutters to trap heat at night.	10-15% reduction in heat loss.
SERVICES (HVAC & ELECTRICAL)	Implement smart ventilation controls to regulate airflow Install ceiling fans with reverse mode for gentle air circulation.	5-10% reduction in mild heating demand.
SPACE PLAN & INTERIORS	Optimize thermal mass by exposing brick walls to capture solar warmth. Rearrange office spaces to maximize natural sunlight exposure.	5-10% passive heating efficiency improvement.

Table 5: Winter retrofitting scenario

The third and last proposed scenario examines aims to balance heating, cooling and natural ventilation needs, focusing on the equinoxes during spring and autumn. The weather for the majority of the year is pleasant, with temperatures varying between 18°C to 25°C with moderate humidity and no need for active heating or cooling. However, heritage buildings such as Al Ahram, experience seasonal fluctuations and need a balanced strategy to transition seamlessly between heating and cooling seasons while maintaining stable indoor temperatures.

BUILDING LAYER	PROPOSED RETROFITTING MEASURES	ENERGY IMPACT
SKIN	Operable external shutters to adapt to changing daylight conditions. Adjustable secondary glazing (open during mild weather, closed for insulation). Use phase change materials (PCMs) in ceilings or walls to regulate indoor temperatures.	15-20% reduction in heating & cooling demand.
SERVICES (HVAC & ELECTRICAL)	Implement dynamic HVAC control systems that switch between heating & cooling as needed. Use ceiling fans and stack ventilation to enhance airflow. Optimize natural daylighting to reduce artificial lighting use.	20-35% total reduction in seasonal energy use.
URBAN CONTEXT & ADAPTATION	Promote rooftop solar PV integration for energy self-sufficiency.	10-15% reduction in long-term energy costs.

Table 6: Equinoxes retrofitting strategy

5.3. Energy Comparison

Effective retrofitting requires a nuanced approach that balances energy efficiency, heritage preservation, and user comfort. The three scenarios presented cater to Alexandria's distinct seasonal demands while reflecting insights from the various strategies presented. The Summer Optimization scenario focuses on reducing cooling loads by enhancing the envelope layer, optimizing ventilation, and offering the highest energy savings but requiring moderate investment. The Winter Optimization scenario prioritizes thermal comfort and energy conservation by upgrading the envelope and services layers to reduce heat loss, making it cost-effective and minimally invasive. In contrast, the Equinox Optimization scenario takes a wider approach, simultaneously targeting multiple layers—envelope, space plan, services, and finishes—to handle transitional conditions with dynamic solutions like adjustable shading and smart controls, providing balanced year-round performance. While all three scenarios share a commitment to reversible, minimally invasive measures that preserve heritage aesthetics, they differ in focus, investment, and complexity.

Criteria	Summer Optimization	Winter Optimization	Equinox Optimization
Estimated Energy Savings	15-25% reduction in cooling loads	10-15% reduction in heat loss	15-20% reduction in heating & cooling demand
Cost	Medium- 30-50% of full retrofit budget	Low-Medium 20-40% of full retrofit budget	Medium-High 40-60% of full retrofit budget
Disruption Levels	Low- Phased implementation possible	Low- Minimal invasive work needed	Moderate- Staggered implementation required
Heritage Sensitivity	Low impact, reversible interventions	Preserves heritage features, non-invasive	Balanced approach, adaptive and respectful of heritage

Table 7: Scenario comparison between the three proposals

6. CONCLUSION AND RECOMMENDATIONS

6.1. Summary of Key Findings

The analysis of the three seasonal scenarios demonstrates how context-sensitive retrofitting can effectively balance energy efficiency with heritage preservation. By adopting a layered approach, critical issues in the original building—such as poor insulation, single-glazed windows, outdated materials, and inefficient systems—were identified. The proposed scenarios implemented effective solutions, including modern insulation, double glazing, efficient HVAC systems, and photovoltaic cell integration. This methodological approach detects major sources of energy waste and mitigates them with targeted, context-specific, and heritage-aware solutions.

6.2. Holistic Strategy

Retrofitting commercial buildings for energy efficiency is crucial in promoting sustainability, reducing environmental impact and aligning with global climate goals. In Alexandria, this approach not only optimizes energy performance but also preserves the city's unique cultural identity by maintaining architectural heritage. A holistic retrofitting strategy embraces the concept of viewing the building as a collection of interconnected layers—structure, services, space plan, and finishes—allowing for accurate waste estimation and targeted, efficient, and minimally invasive interventions. By implementing tailored strategies that respect each layer's role and heritage value, buildings like Al Ahram can reduce energy consumption, enhance indoor comfort, and extend the lifespan of historic structures while maintaining their cultural significance.

6.3. Policy Recommendations and Action Plan

Recommendations focus on three main points:

Governmental Involvement to streamline permitting processes and provide technical support for retrofitting heritage buildings and provide tax breaks or grants to encourage energy-efficient upgrades.

Education and Awareness to engage stakeholders, including building owners, engineers, and conservationists, to align interests and expectations. As well as raise awareness about the long-term benefits of retrofitting through educational programs and campaigns.

Further Studies and Research comprehensive studies must be conducted on context-sensitive retrofitting techniques for heritage buildings. Investigate innovative materials and technologies that balance energy performance and heritage preservation.

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THE INFLUENCE OF OPEN SPACES ON THE QUALITY OF LIFE AND THE USERS' PERCEPTION OF THE CITY: THE CASE OF WATERFRONT DEVELOPMENT OF JAZAN CORNICHE, SAUDI ARABIA

Muna G.M. Ahmed

THE INFLUENCE OF OPEN SPACES ON THE QUALITY OF LIFE AND THE USERS' PERCEPTION OF THE CITY: THE CASE OF WATERFRONT DEVELOPMENT OF JAZAN CORNICHE, SAUDI ARABIA

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Public Open spaces are significant elements of the urban structure of the city. A well-designed public open space positively contributes to the quality of life, it motivates the residents to socially interact, engage, communicate, and strengthen their sense of belonging to the place. Urban waterfront areas in coastal cities are valuable spaces that have a vital role in representing the overall identity of the city. The study investigates the key elements essential to integrate urban form components and the users' experience. The main objective of the methodological approach is to understand citizens' preferences and opinions on the renovations of Jazan Corniche in three selected locations. The research tools include a literature review, socio-spatial analysis, field observations, and an online questionnaire survey. Based on the performance of the existing urban waterfront spaces in Jazan Corniche considering infrastructures, landscape, and facilities, the conclusions highlight the potential for further design recommendations and future modifications to encourage urban planners and designers to consider community interest and develop urban open space that can positively influence the quality of life and the users' perception of the city.

1. INTRODUCTION

Public open spaces are described as available and freely accessible to all users and are classified to more than eleven types of spaces, one of which is waterfronts[1].Waterfront is defined by Cambridge Dictionary as "a part of a town that is next to an area of water such as a river or the sea"[2] . The urban waterfront is associated with urban area overlooking natural or artificial water body[3].Urban waterfront areas in coastal cities are valuable spaces that have a vital role in representing the overall identity of the city, they are considered as unique types of public spaces with distinctive urban character as an urban edge, where the edge of land extends to water, they represent a specific combination of urban and natural environment within the urban fabric of the city , and holds significant importance in shaping cityscapes[4] . Urban waterfront are areas of strategic and high economic value in cities, they bring numerous social, environmental, and economic benefits to the communities[5] .Waterfronts play an important and strategic role in transforming the structure of coastal cities to attract investment[6]. Each city's waterfront has a different character and place identity that influence the mental maps of the city and urban imagery in general. Cities around the world are trying to utilize their unused waterfront, many coastal cities implement projects to regenerate their waterfronts and stimulate the growth of the economy as well as enhancing the cultural experience for the users[7]. For a successful waterfront, it should reflect the life quality and strengthen the city image for inhabitants and visitors[8].

1.1. Jazan Waterfront and Corniche

Jazan City is a port city, the capital of Jizan Region, located on the Southwest coast of Saudi Arabia on the

Red Sea, directly North of Yemen. It began as a cluster of dispersed settlements that developed to a consolidated centre with a multitude of land features and functions. The city grew concentrically, with a natural proclivity towards the seafront. The city has a linear pattern on the North-South axis along the 15kilometre long coastline[9] , which is considered as one of the main constituents that has formed the city's identity because of the unique location and length of the coastline. Waterfront or corniche has a special position in the urban composition and visual identity of the city. In recent years a number of projects and rehabilitation initiatives were implemented in Jazan corniche, the research aims to evaluate the citizens' preferences and opinions on the renovations of Jazan Corniche in three selected locations, and also study their influence on the quality of life and the users' perception of the city

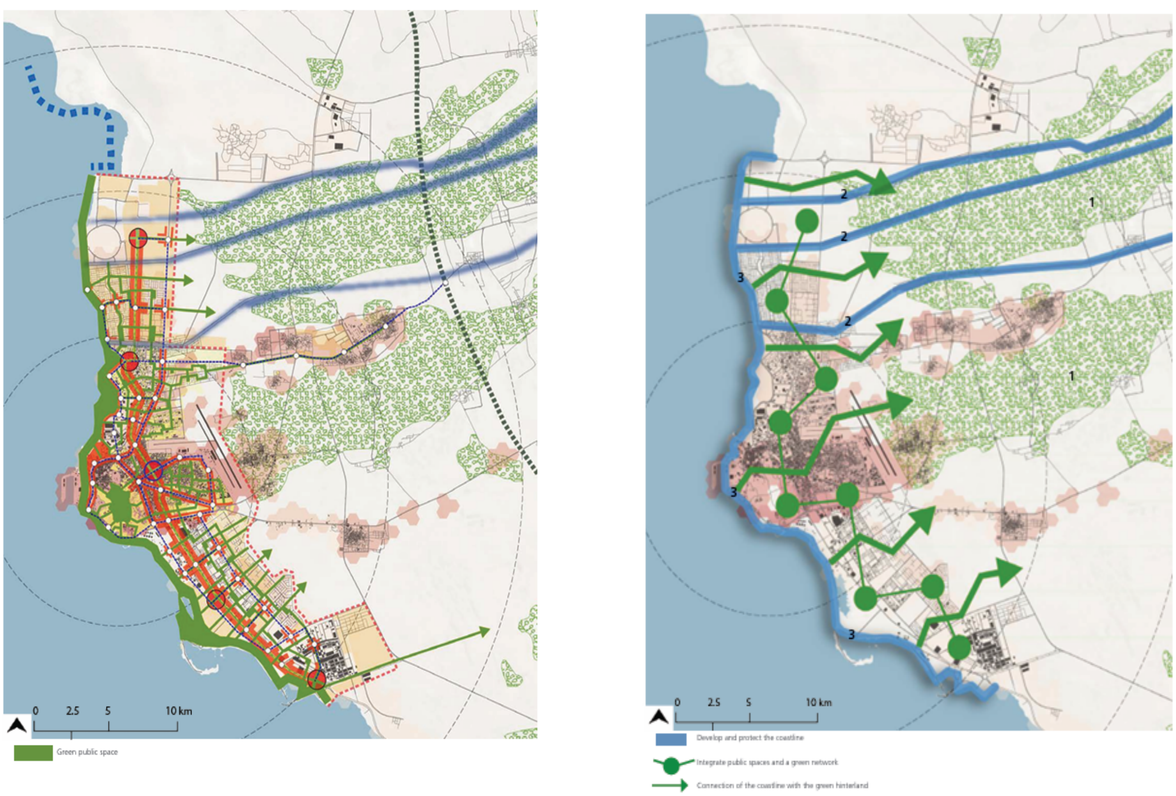

Fig. 1: The strategic vision for Jazan coastline as a defining attribute in the city's character. (Source: Ministry of Municipal and Rural Affairs and United Nations Human Settlements Program. Future Saudi Cities Program: Jazan City Profile, 2019).

1.2. Objective of the Study

The main objectives of the study are:

- To understand citizens' preferences and opinions on the renovations of the Corniche areas.
- To investigate the influence of waterfront public open spaces on the quality of life in Jazan city.
- To examine the features that contribute to the quality of public open spaces in waterfront areas.

- To determine the key elements essential to integrate urban form components and the users' experience for the future developments in Jazan Corniche.

2. THEORETICAL REVIEW OF ASSESSMENT AND EVALUATION TOOLS OF URBAN PUBLIC OPEN SPACES:

Several research considering the evaluation of urban environments quality and the user's perspective on urban public spaces includes ten dimensions[10]: sense of belonging to the place, Satisfaction, users experience, functions & activity, safety, Health, Climate, accessibility, Universality, management. The following tools were reviewed for this research:

2.1. Public Space Characteristics Observation Questionnaire (PSCOQ) Tool

The Public Space Characteristics Observation Questionnaire (PSCOQ)[11] measures three general characteristics of public spaces described in Table (1)

CATEGORIES	SUB CATEGORIES	CONTENTS
Architectural Characteristics	Accessibility	Open/closed area, public service stop, private/restricted areas, parking areas, stairs, regulation, levelling and maintenance of the pavement, access and transit for people with reduced mobility, difficulty in walking
	Views	Visually attractive for walking, views-attractive, perspective-sensation of spaciousness (unobstructed view), enclose/isolated by natural features, buildings or a combination of both
	Areas	Children, animals, sports, gardens, water, pergolas or trees providing sun protection, sculptures
Functional Characteristics	Services - resources	Public bathrooms, water fountains, food outlets, public eating area, litter bins, benches and seats
	Signage	Nominative, indicative, informative, advertising, notice board
Contextual Characteristics	Safety	Opening and closing times, security personnel, security cameras, areas with slippery surfaces, visibility to the outside or surrounding buildings, emergency vehicle access and parking
	Lighting	Lighting level at night, dark areas, maintenance of lighting elements
	Cleanliness	papers, animal droppings, dead animals, tobacco, strong smells (rubbish, urine, etc.)
	Physical order	Abandoned areas, flooded areas, broken walls-barriers, boarded-up or dilapidated buildings, vegetation growth over pavement, abandoned items, vandalism, burnt elements, theft of vegetation, graffiti
	Absence of noise	Own, external
	Presence of sensorial elements	Fragrant plants, color variety in vegetation, bird habitat, sound of moving water

Table 1: Content of the PSCOQ instrument. Source: Lorenzo,M. et al. (2023) Quality analysis and categorization of public space, Heliyon , Volume 9, Issue 3,2023, e13861, ISSN 2405-8440

2.2. Importance Performance Analysis (IPA)

Importance Performance Analysis (IPA) is a useful tool that can be used for waterfront public spaces evaluation, the criteria summarized as follows[12]:

VARIABLES	INDICATORS
infrastructure	Availability of recreational facilities Availability of lighting facilities Availability of sports facilities (field, outdoor fitness, jogging track) Quality of infrastructure (drainage, clean water)
Access and Linkage	Quality of pedestrian paths Availability of facilities for disabled people Availability of vehicle parking space Access to public and private transportation
Comfort and Images	Security in public spaces Sound/noise comfort level Environmental cleanliness Availability of shading vegetation
Uses and Activity	Interaction among visitors Existing community activities Diversity of visitor ages Availability of various informal sectors/ street vendors

Table 2: Importance Performance Analysis (IPA) variables**.** Source: Suminar, L et al. (2024). "Assessing Urban Waterfront Public Space Service Quality Using Importance Performance Analysis (IPA)". ARTEKS: Jurnal Teknik Arsitektur 9 (2)

2.3. Mixed-Methods Approach

To determine the parameters and features of a well-designed public open space that fulfils its functions, enhance social cohesion, and increase users' satisfaction, a set of features are categorized according to their nature into two main categories[13]:

VARIABLES	INDICATORS
Qualitative features	Accessibility and Walkability Adaptability to people uses & needs Environmental sustainability Safety cultural values and character
Physical Features	Street furniture and accessories Protection from various weather conditions Greenery Infrastructure facilities Natural landscape or attraction elements Landmarks Recreational areas Sports Facilities Food options and economic activities

Table 3: Mixed-methods approach variables. Source: Filiz Karakus, Juman Hasan. (2023). Assessing The Urban Public Spaces in Heart of Sharjah: A Mixed-Methods Analysis. Journal of Namibian Studies: History Politics Culture, 39

2.4. Psychological Place Attachment Scale (PPAS)

The Psychological place attachment (PPAS)[14] assesses people feelings toward a particular place through a number of statements on a 5 Likert scale, it has both an original long form (30-item) and a short form (13 items). The short form (PPAS-SF)[15]: participants rate the following statement about the place name (filled in blanks) using the scale (Strongly disagree – disagree – neither agree/disagree – agree – strongly agree)

1. I feel happy when I am in ___________.
2. I expect to have significant memories of _____________ after I leave.
3. I don't care about what happens in ____________.
4. I feel secure when I am in _________.
5. __________ has a special meaning for me.
6. I keep up with the news about ___________ no matter where I am.
7. I would not feel sad if I had to leave _______________.
8. I don't feel I belong to _________________.
9. I like _____________.
10. I will forget about ______________ if I move away.
11. ______________ is not a comfortable place for me.
12. ______________ seems unfamiliar to me.
13. I feel relaxed at _______________.

3. RESEARCH METHODOLOGY

The researcher adopted a mixed-methods research approach to evaluate the urban environments quality and explores urban residents' responses and user's perception of urban public spaces. The Methodology is a combination of qualitative and quantitative analysis which include: a literature review, socio-spatial analysis, field observations, and an online questionnaire survey. The designed questionnaire comprises two main sections. The first section encompasses respondents' basic information including age, gender, education level, city of residence, household type, frequency of visits to corniche, and duration spent in visits. The second section focuses on assessing the respondents' satisfaction, preferences and opinions on the renovations of Jazan Corniche in three selected locations, using Likert's five-point integral scale.

Method	DESCRIPTION
Socio-spatial analysis	Socio-spatial analysis included multiple field visits, a photographic survey and desk research (analysis of satellite images of the site, arial photos of the area). Based on the analysis and a basic overview of the area and the topic, the waterfront was divided into three sites, each sites have a specific atmosphere and different identity
Observation	The researchers visited the three sites in order to create a mental map, record brief notes of how users interact with the waterfront public space and take photographs. The visits were done at different time periods on weekday and weekends, to observe how people behave and interact with their surroundings "behavior patterns" on various occasions to have "subjective assessments" and provide clues to explain what is actually happening.
Comparative analysis	The comparative analysis for the three sites is done based on five dimensions: a) architectural and urbanistic features, b) socio-relational characteristics, c) functional aspects, d) morphological and social parameters, e) local culture and climate of the context. An illustrative comparative analysis is performed to demonstrate the key differences between the selected sites.
Online questionnaire survey	A questionnaire survey was conducted online on 4th Dec.2024 –20th March 2025. It aimed to a) understand citizens' preferences and opinions on the renovations of the Corniche areas, b) identify the main characteristics and unique features as perceived by users. A total number of 101 questionnaires respond were collected. The results were analyzed and evaluated.
Analysis and Synthesis and Conclusions	Based on the socio-spatial analysis and questionnaire, the key elements essential to integrate urban form components and the users' experience for the future developments in Jazan Corniche are concluded.

Table 4. Methods of the research. Source: Author

3.1. Study Area

The study considered Jazan city waterfront and corniche area which has a linear pattern on the North-South axis along the 15kilometre long coastline, it is considered as one of the main constituents that has formed the city's identity because of the unique location and length of the coastline. Waterfront or corniche has a special position in the urban composition and visual identity of the city. In recent years a number of projects and rehabilitation initiatives were implemented. Three sites were included in the study:

A. The Northern corniche which includes three locations: sun set view area, sun set greeting square, the cultural boulevard area, and north corniche park.
B. The central corniche near the old Amana or happy times corniche near Farasan ferry passenger's terminal.
C. The Southern corniche near the Heritage village museum.

The three sites location is illustrated in Figure 2.

Fig. 2: The geographical location of the selected sites in Jazan waterfront area: a) The Northern corniche; b) The central corniche; c) The Southern corniche.

3.2. Socioeconomic Characteristics of the Respondents

The socioeconomic characteristics of the questionnaire respondents are illustrated in Table 5

SOCIOECONOMIC CHARACTERISTICS OF RESPONDENTS

Sex	Men	31.7%
	Women	68.3%
Age Group	<18 years	5%
	18-25	63.4%
	26-60	28.7%
	>60	3%
Educational level	University degree	83.2%
	Secondary /primary	13.9%
	others	3%
City of residence	Jazan	93.1%
	Other city	6.9%
Marital Status	Single	68.3%
	Married with children	29.7%
	Married without children	2%
Housing Type	apartment	49.5%
	Villa	13.9%
	Tradition house with yard	27.7%
	Others	8.9%

Table 5. The socioeconomic characteristics. Source: Author

4. RESULT

4.1. Participants Preference Sites in the Corniche Area

The percentage of participants who have visited the selected sites of the corniche

The Northern corniche	North corniche park	91%
	Sun set view and greeting square	88.1%
	The cultural boulevard area	93.1%
The central corniche	near the old Amana	76.2%
The Southern corniche	near the Heritage village museum	91%
How many times you go to the corniche	Once per week	48.5%
	Once per month	28.7%
	Only on occasions	22.8%
	never	0%
Average time spent per visit	Less than 1 hour	16.8%
	1-3 hours	66.3%
	More than 4 hours	15.8%
	never	1%
	Sitting with family and friends	95%
	Walking, jogging	61.4%
	Play, entertainment	32.7%
	Cultural and sport events	22.8%
	Other	5.9%

Table 6. Participants preference sites in the Corniche area. Source: Author

4.2. Participants Perception and Satisfaction of the Selected Sites in Jazan Waterfront Corniche

Participants perception and satisfaction	Very unsatisfied	Unsatisfied	Neutral	Satisfied	Very satisfied
How satisfied you are with the overall design of the waterfront corniche areas in Jazan	3%	9.9%	32.7%	25.7%	28.7%
How satisfied you are with seating distribution and benches design	3%	18.8%	27.7%	25.7%	24.8%
How satisfied you are with sports facilities (field, outdoor fitness, jogging track) design and material	3%	7.9%	13.9%	39.6%	35.6%
How satisfied you are with lighting facilities, broadband networks,	7.9%	9.9%	27.7%	23.8%	30.7%
How satisfied you are with safety for children and separation of cars from pedestrian routes	5%	9.9%	19.8%	27.8%	36.6%
How satisfied you are with the availability of facilities for disabled people	5%	7.9%	29.7%	19.8%	37.6%
How satisfied you are with the availability of food/coffee outlets	4%	7.9%	24.8%	25.7%	37.6
How satisfied you are with the availability of public bathrooms, first aid station	10.9%	13.9%	26.7%	18.8%	29.7%
Do you think that the renovations of Jazan Corniche positively motivate the residents to socially interact	1%	6.9%	14.9%	29.7%	47.5%
Do you think that the renovations of Jazan Corniche positively contribute to the quality of life and enhance the city image	1%	0%	5%	17.8%	76.2%
What is your overall satisfaction about the corniche waterfront area in Jazan	1%	5%	18.8%	30.7%	44.6%

Table 7. Participants perception and satisfaction of the selected sites in Jazan waterfront corniche. Source: Author

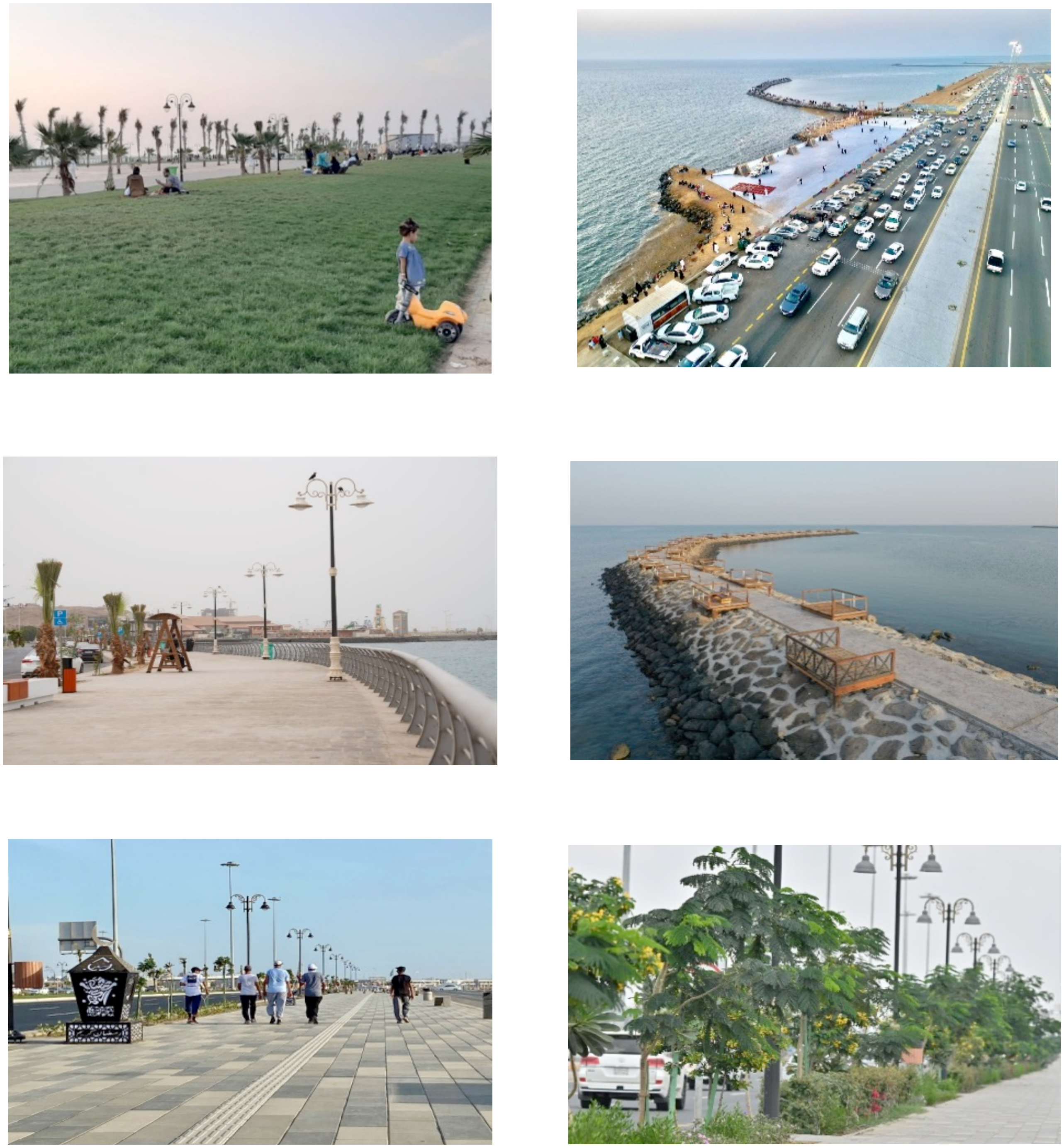

Fig. 3: Photographs of the three selected sites in Jazan Corniche

4.3. Results Summary

The main findings of the study (Table 7) can be summarized as:

The levels of overall satisfaction of participants about the selected sites in Jazan corniche waterfront area were relatively high 95% (combined 45% very satisfied and 30% satisfied).

The user's perception about the renovations and developments of Jazan Corniche, and their influence on the quality of life and the city image scored 94 % with more than 75% very satisfied.

Frequency of visit and average time spent: The northern corniche three locations are the most frequently visited sites with (93.1%, 91%, 88.1%).and the average time spent in these sites is 1-3 hours per visit for almost 66% of the visitors.

The satisfaction with the physical features: Respondents were most satisfied with the sports facilities and availability of walking and jogging track, scored almost 75%, and the availability of food and coffee outlets scored 63.3%, while the distribution and design of seating benches and decks was only 50.5% with 77.8% have remarks on the design of seating and benches as they prefer to sit on the ground rather than seats and benches. On the other hand, the availability of public bathrooms, first aid station scored 24.8% (combined very unsatisfied and unsatisfied)

The satisfaction with qualitative features: The accessibility and availability of facilities for disabled people scored 13% unsatisfied users and 57.4% were satisfied and very satisfied. As for safety participants satisfaction with safety for children and separation of cars from pedestrian routes (satisfied and very satisfied combined was 64.5%) and 15% were (combined very unsatisfied and unsatisfied). The most commonly reported concern among participants was inadequate shaded areas and other features for protection from various weather conditions (61.1%) commented on the need to provide sufficient shades on seating areas. Also concerns and comments on the insufficient signage and location maps in the three sites, (52.8%) of the respondents were unsatisfied with the availability of signage.

5. DISCUSSION AND CONCLUSIONS

In conclusion, the findings of the study confirmed the influence of public open spaces in urban waterfronts areas on the quality of life of city citizens and positively strengthened their sense of belonging to the place, as well as enhancing the city image. Contextual, functional, and architectural characteristics resembled by accessibility, physical order, attractive view and urban design features are key elements for a well-designed public open space. The variability of individual waterfront character areas, with different identities, functions, and uses is vital to strengthen the (people-city-sea) relationship and play a pivotal role in the reconstruction of the identities of cities, therefore, it should be preserved. Preservation of place identity contribute to the uniqueness, competitiveness, and sustainability of the place, the development of long-term vision for waterfront areas is highly recommended [16].

6. Recommendations

The following issues are to be considered for future developments of waterfront of jazan corniche:

- The development of long-term vision for waterfront areas.
- Quality of seating in terms of dimensions, design, materials and location.
- Provision of sufficient and good quality signage.
- Provision of emergency facilities in each location.
- Provision of sufficient public toilets in terms of quantity, design location and accessibility.
- Design quality and aesthetic value of street furniture, fences, pavements.
- Consideration of environmental aspects and provision of shaded areas.
- Application of sustainable solutions, clean energy.

ACKNOWLEDGMENTS

The views and opinions expressed in this paper are those of the authors and do not necessarily reflect those of their institutions

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Traditional Dwellings and Settlements

Working Paper Series

TRADITIONS OF RAINWATER HARVESTING AND COSMOPOLITANISM: THE CASE OF JAIPUR (RAJASTHAN, INDIA)

Savitri Jalais

TRADITIONS OF RAINWATER HARVESTING AND COSMOPOLITANISM: THE CASE OF JAIPUR (RAJASTHAN, INDIA)

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Did the cosmopolitanism present in the court of Jai Singh II influence the hydraulic structure of Jaipur, this "new city" designed at the beginning of the 18th century in the semi-arid region of Rajasthan in India? The essential conditions for the creation of a city is the availability of water, the need for water transcends all borders. This article shows that cosmopolitanism cans be seen/is present in the elaborate network of water systems found in the region, and always existed in the form of transfer of technical knowledge. Just as Jai Singh II rooted his capital city on existing traditions while at the same time was open to inventions/discoveries prevalent in his time for the invention of astronomical measuring bodies, so too, the water system on which the city was built speaks of such exchanges/cosmopolitanisms.

1. INTRODUCTION

This article questions the relevance of using the term cosmopolitanism regarding the hydraulic heritage of the city of Jaipur in India. In this "new city" designed at the beginning of the 18th century in the semi-arid region of Rajasthan, an elaborate network of water systems was planned so as to literally "harvest" water, or in other terms collect and manage rainwater for the needs of the city. The water structures that emerged were extremely sophisticated, adapted to a specific landscape, and present at different scales – from domestic wells, step-wells (*baoli*, *vav*), reservoirs, basins (*kund*), to large urban lakes (*talab*). They reflect a hydraulic tradition that is multicultural – Yemenite, Persian, Ottaman, Roman – , embraced and developed in western India, particularly in today's Rajasthan and Gujarat and exported during the Mughal period (16th-18th century) by the Rajput Kings that served in different parts of the Indian subcontinent as ministers of the Mughal emperor.

These water systems, developed through many centuries and reflecting know-hows of various cultures were progressively abandoned during the British colonial era (19th-20th century) so as to implement new systems with different logics such as dams, pipelines and bore-wells. The layout of these new infrastructures, continued since by the Indian government, seem to have been implemented at the expense of the traditional system. Therefore, is the term cosmopolitanism still appropriate to describe Jaipur's current water system, in the true sense of the word, cosmopolitanism implying the possibility for different cultures and traditions to live and work hand in hand, and integrate one with the other?

Could the revival of these vast and ancient water structures, unused but still visible today in Jaipur's landscape, integrate in the future a more holistic « cosmopolitan » approach? First of all, can their multicultural tradition be revived or at least serve as examples in the elaboration of new hydraulic structures as promoted by Anupam Mishra in his book « Rajasthan Ki Rajat Boonden » (The radiant raindrops of

Rajasthan)[1], a book read and recited daily in remote villages of Rajasthan in the 1990s as an ode to what has become « local knowledge »?

Secondly, the hydraulic heritage present in the city of Jaipur testifies of wisdom that have been constantly adapted to the specificities of the semi-arid region of Rajasthan and the city of Jaipur. Can they be valorized today and transplanted in other arid or semi-arid regions of the world or are they necessarily linked to a particular culture? Is it possible to sort out those elements and devices that are universal from those that are local, specific to a place?

Thirdly, can the memory of water still act as a major element of public space in Jaipur's urban fabric, water's role extending beyond drinking or domestic use, to a symbolic use? The past is constantly redefined and operationalized for the purpose of future and more appropriate needs. In the wake of global warming, we can imagine these structures playing yet other roles in the design of public spaces and in creating islands of freshness within an urban setting.

2. THE PREREQUISITE/REQUIREMENT OF WATER FOR A COSMOPOLITAN CITY

One of the essential conditions for the creation of a city is the availability of water, however the city of Jaipur is better known for its urban layout on a nine squared Mandala (1727)[2] the architecture of its palaces that are of Mughal style[3] and the building of a grand astronomical observatory called Jantar Mantar (1725)[4] , by Jai Singh II (1688-1743), Prince of Amber (Fig. 1). The fortified city of Amber, nestled on a hillside and located on a strategic defensive position since 966 AD., could no longer reply to the incessant need of water and space for a population that kept growing, and was thus abandoned. The new capital, Jaipur, "the city of victory" in Hindi, was planned to inhabit 50 000 inhabitants and become a commercial platform thanks to its strategical position on the road from Delhi to the ports of Gujarat (Salam, 2011).

Jaipur is located at the edge of the Thar desert however little is known of the vast hydraulic system on which the city was founded, a very important issue in this semi-arid region where one remembers, the Mughal Emperor Akbar, had to abandon Fatehpur Sikri, the new city he had designed in 1569 for lack of water. One of the reasons for practically abandoning the old city of Amber was also because of lack of water, the water present seem to have been causing sicknesses. The site chosen at the foot of the Aravalli mountains 11km from Amber, was a flat and dry plain bed of a lake between rivers Amanisha and Dhond. There was good drainage conditions and availability of stone for construction. A stream ran underground into the town enabling public wells to be built at regular intervals and the houses were connected to a sewer covered with large stone slabs, which remind of the Nawabi drains erected by the Mughals in numerous Indian towns.[5] The city was built on agricultural land and it is presumed that the numerous wells and water structures present for irrigation purposes were conserved, extended and developed so as to sustain the requirements for this new city. The region was already well versed in this particular architecture specialized in the collection, channeling and storage of rainwater. It had developed in its history a skillful water management network/system adapted to arid zones.

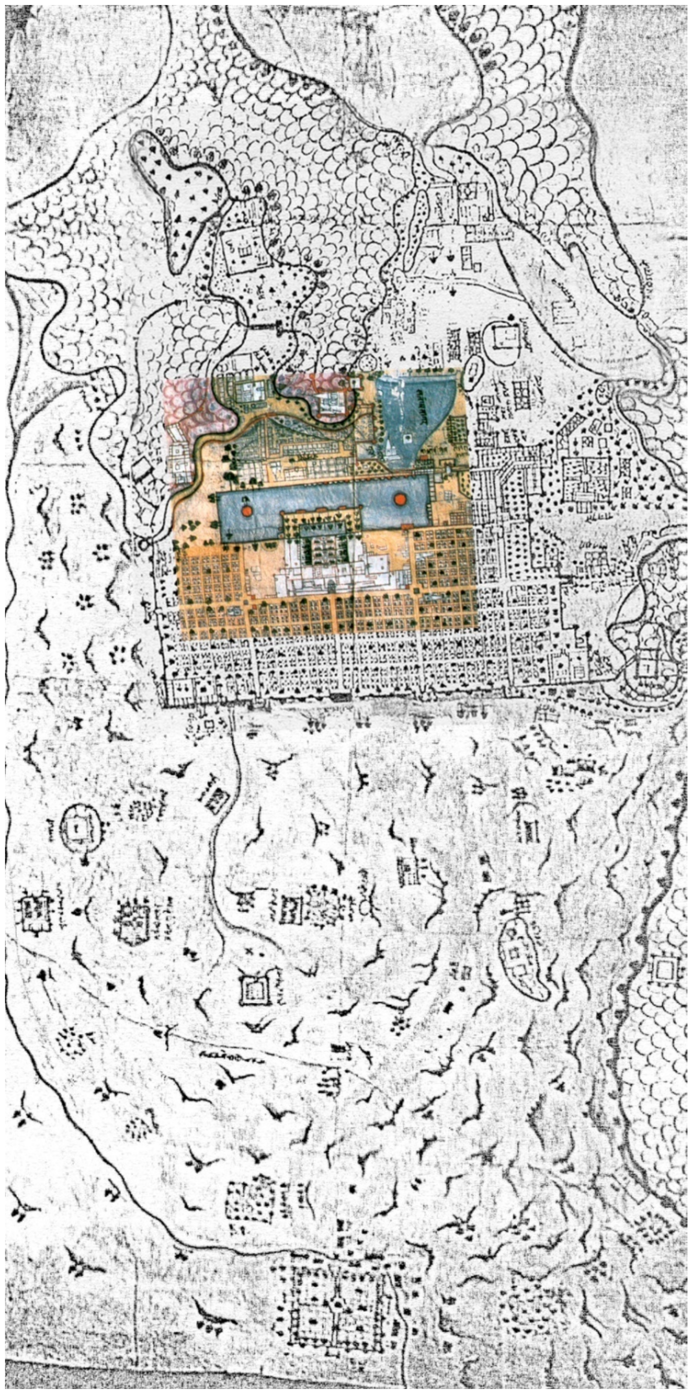

Fig. 1: Plan of the newly built Jaipur city in 1775, and the surrounding water bodies. Jai Singh Museum archives, published in Aman Nath, *Jaipur, the last destination,* 2007, p.58

So as to understand these water structures and the general traditional management of water systems in India it is essential to understand the specificities of the country's monsoon regime, where great quantities of water have to be managed in short periods of time. This is particularly true in Rajasthan, the driest states of India, which has an annual rainfall of just 100 mm in the western to 650 mm in the south-eastern part of the state. In the city of Jaipur, 91% of the annual precipitation (492mm) occurs during the two monsoon months of July and August, and the maximum amount of rain recorded in an hour can amount to 75mm[6]. In these extreme climatic conditions, a sophisticated network of rainwater harvesting was planned, spanning the territorial, urban and architectural scale, so as to collect, store and distribute water. This system allowed the collection and storage of water so as to provide for an initial population of 150,000 inhabitants[7].

Rainwater was harvested on fortified ridges to supply defending forts, on the slopes of the surrounding hills that directed rainwater towards natural and artificial lakes designed with dams and reservoirs and in the ground so as recharge the city's various watersheds. At the bottom of each catchment areas, wells, step-wells (*baoli)* and basins (*kund)* were built to provide water for irrigation, domestic and ritual uses. The city of Jaipur is representative of all these different water harvesting techniques, some through direct rainwater collection, from the top of hills to the plains, and others collecting water indirectly through percolation of ground water. The various elements of this water harvesting system that captures, stores and distributes monsoon water are dams and lakes, basins and reservoirs, wells and stepped wells. Dams are used to retain water in basins formed by the site's natural topography, to form lakes (*talab*), which make it possible to store water while feeding part of the water table. Canals (*nali)*, collect rainwater during the monsoon season and channel it to lakes, cisterns and reservoirs (*tanka*) or basins and tiered ponds (*kund)*. Finally, wells (*kua*), are architectural structures providing access to water, and are supplied by groundwater. Step wells (*baoli)*, are like simple wells, but with a system of steps to provide access to water.

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3. THE ROLE OF JAIPUR'S TRADITIONAL WATER SYSTEM

The city's choice of location is intimately linked to the topography, which creates a natural water reservoir or an upside-down umbrella that is able to catch every single drop of water. The hills surrounding the city form a natural watershed with drainage channels that, over time, have been carefully designed to collect water. The water is also collected through canals, known as *nala*, cut into the rock, which lead the water to the urban lakes. The canals usually follow the contour lines. An ingenious system of counter-slopes on the canals enables sand and dust to be filtered by gravity from the first run-offs. Remains of these canals are still present today.

Fig. 2: The Man Sagar Lake and the city of Jaipur behind, photography Savitri Jalais, 2018.

The city thus is flanked on one side by the Aravalli hills that drain the water into the city and the Man Sagar Lake on the North that used to receive this run-off. This used to prevent floods during the rainy period and provide water all through the year to the ground water that fed the numerous wells. The Man Sagar Lake is an artificial lake or reservoir built by Raja Man Singh in 1610, by damming the Dravyavati river between the hills of Khilagarh and the mountainous regions of Nahargarh (Fig. 2). In the middle he constructed a palace that seems to float in the water and was used for court gatherings and hunting. The lake lies to the north of the city on the road that leads to Amber, it covers 95 hectares and is surrounded by the Aravalli hills to the north, west and east, and intensely inhabited plains in the south. Today, the lake is the recipient of wastewater from the city of Jaipur. The two major canals that drain the surrounding hills of Nahargarh and the city of Jaipur are the Brahmpuri and the Nagtalai *nala*, which bring untreated sewage, in addition to runoff from unpaved streets to this lake, the largest surrounding the city. The depth can vary from 60 centimetres to 5 metres, the width/span is shrinking due to heavy silting, and the effluent from the city's drains has contaminated the surrounding groundwater. The degradation of Man Sagar began in the 1990s, with the government's decision to dump Jaipur's sewage into the lake. The volume of water in the lake has been estimated at 3,130,000 cubic meters at maximum water level. During the dry season, from October to June, this figure descends to around 360,000 cubic metres. The lake is today visited by most of the tourists that come visit the cities of Amber and Jaipur. The stored water is essentially used for irrigation at the downstream end of the lake during the summer months, resulting in a drying up of the lake during these months. The lake's water level also depends on the water table, which is being depleted very rapidly in the vicinity of Lake Man Sagar, due to the unprecedented extraction of groundwater resources.

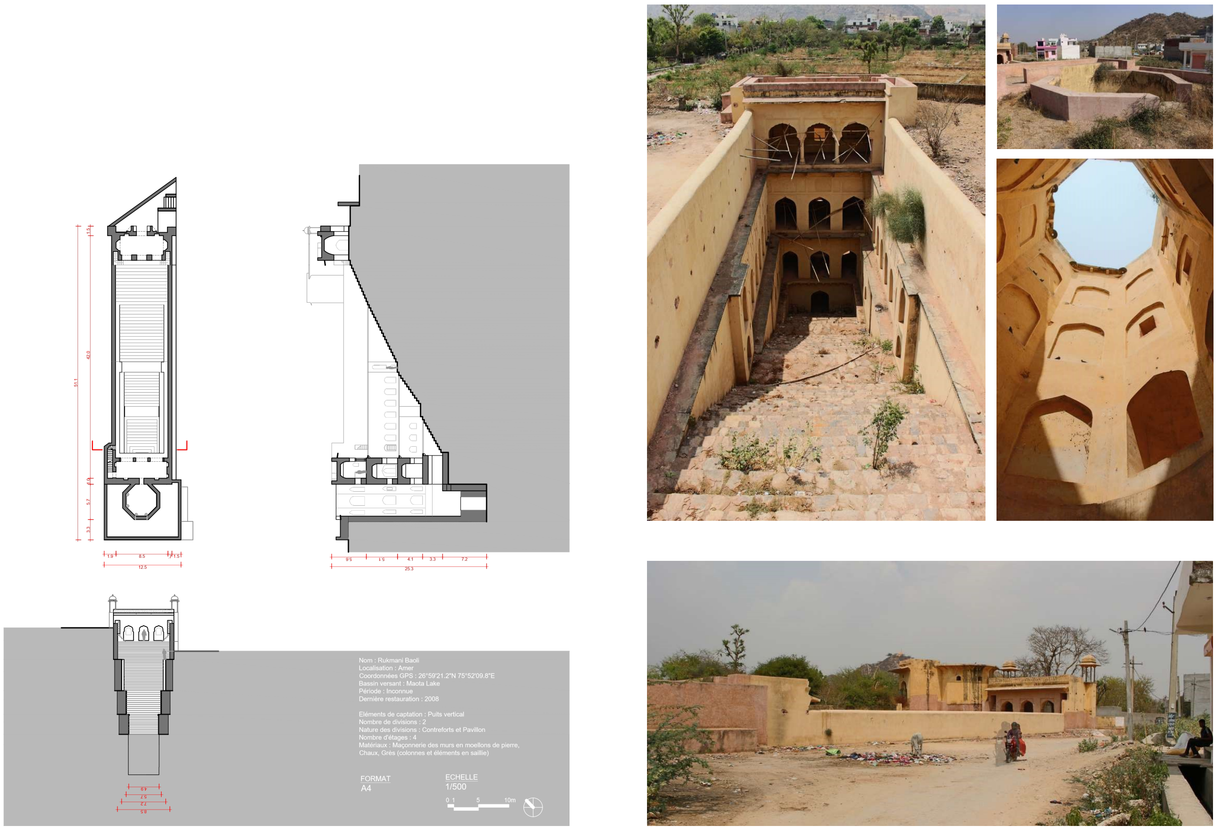

Fig. 3: Example of a *baoli*, Rukmani *baoli* measure drawing and photography Léonore Lagrange, 2018

Baoli or stepwells are narrow underground structure that provides easy access to the water level (Fig. 3). In its most developed form, a *baoli* is made up of three architectural elements: a vertical shaft with surface structures that allow water to be drawn from ground level; a staircase running from the entrance pavilion to the lower level of the shaft; and a number of intermediate pavilions connected by cornices. There are 18 *baoli* present in Jaipur, all of them located at the bottom of the valley near lakes or natural depressions. For example, the map shows that as many as six *baoli* are present around the Man Sagar Lake. Reminds us of the primary function of a *baoli* which is to capture a maximum quantity water, which depends on the level of the surrounding groundwater level. The key is to locate the water table at its highest and to ensure its constant recharge thanks to the infiltration of precipitation that feeds the ground water table. They were initially located on the outskirts of the city, in agricultural land or in gardens. When the city of Jaipur was built, some of them were incorporated within the urban fabric. Il was subsequently difficult to construct such monumental structures inside the city and so simple wells (*kua*) were constructed instead.

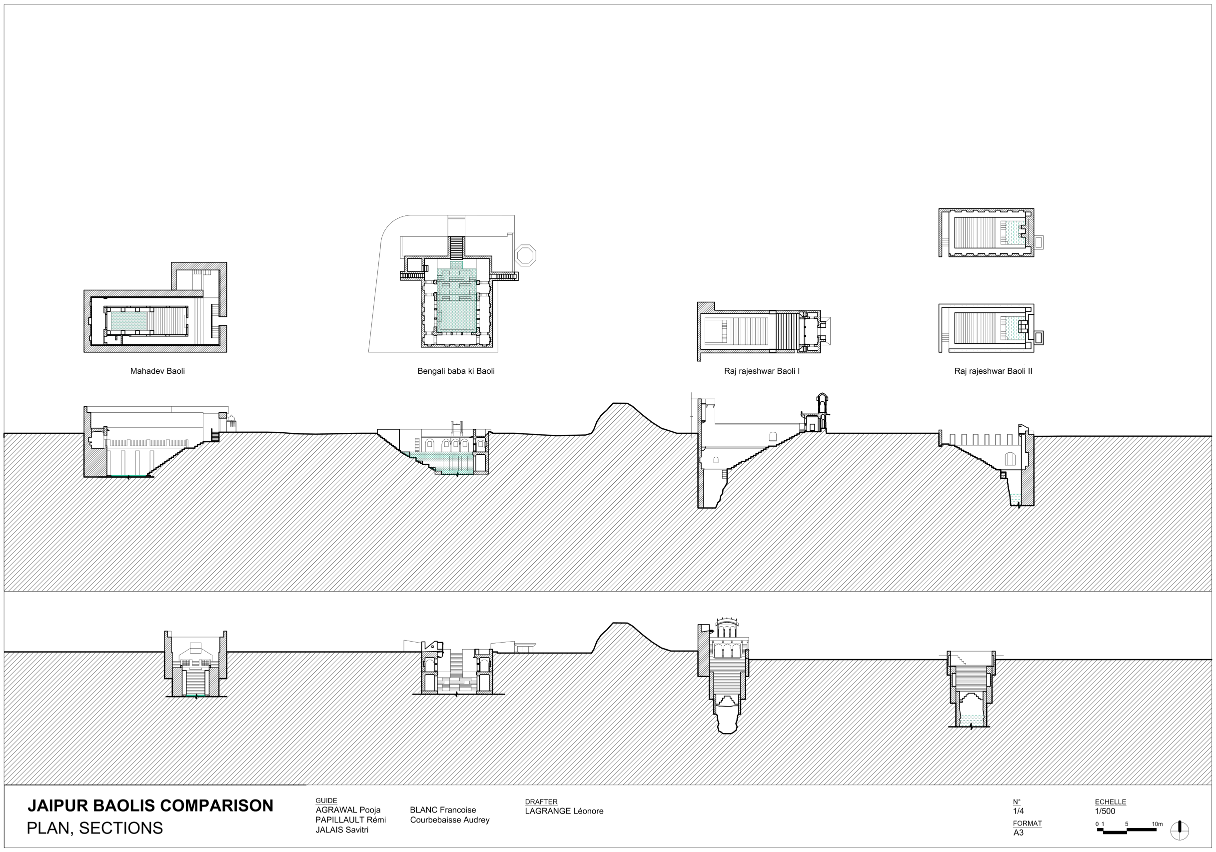

Fig. 4: *Baoli* vary in size, form and orientation, measure drawing Léonore Lagrange, 2018

Baoli are composed of a reservoir and a flight of stairs that link the ground/street level to the water level. They are often rectangular, narrow and linear in shape. In section, it forms a triangle, composed of a horizontal line at ground level, a vertical line that sinks deep into the earth and a slanted line following the diagonal of the stairs. The system of groundwater capture is a vertical well, or a simple square pit which goes down to the water table. In his book, *The Iconography of water*, Frederic W. Bunce explains that classic wells could be dug where the water table was relatively close to the ground. Where the groundwater table was more than 6 or 7m below ground level, a *baoli* was built, not only to provide access to water, but also to provide a cool respite from the scorching heat of the dry season. During the monsoons, the tank can also collect rainwater, like a cistern. (Victoria Lautman, *The Vanishing Stepwells of India*,). However, it is more efficient in capturing water from the ground, the *baoli* gets filled up proportionally to the rise in groundwater level. Actually, the reservoir being of a big size, the volume of water that percolates in a *baoli* is much greater than that of a well. This is reflected in a popular saying "*panch kuva barabar ek vav*", one *baoli* is equivalent to five wells. The dimensions of *baoli* are varied (Fig. 4). With time, they embellished, and these wells ended up resembling underground buildings and palaces. These various forms and sizes can be explained by geological conditions: deeper the water table, longer will the *baoli* need to be so as to respect a comfortable descent. The water needed for a certain community can also influence the size of the *baoli*, as it is clear that the larger a *baoli*, the greater its water capacity will be. Each *baoli* has above its rim and around its perimeter a system to draw water from the well/reservoir.

The cases we have seen above depicts the simplest way to access water: by digging a well, whose function is to capture groundwater. The location of a well depends therefore on the presence of a groundwater and its level of water. As a result, wells are frequently found in plains and valleys and are non-existent on slopes and ridges. Furthermore, those wells dug in built-up area are exposed to the risk of water pollution.

In a city like Jaipur, where forts are built on the mountain ridges, it was important to find other ways to provide pure and abundant water, whatever the context and morphology of the land. Devises were thus designed to harvest water directly, to capture and conserve it, even on slopes, ridges or in densely built-up areas. Such is the function of the traditional water reservoirs, called *kund*, *tanka* or sometimes *jhalara* , artificially constructed basins of various shapes and sizes. The oldest example of a reservoir with steps can be found in the Uperkot caves in Junagadh, dating from the 4th century. They take the form of a pit, the walls of which are generally made up of steps with a more or less steep slope to allow access to the water level. They generally collect run-off water, and are often used for religious and ritual purposes, enabling ablutions and baths, but some are also purely utilitarian, simply supplying water to a site. Anupam Mishra poetically describes these structures:

> "The principle is simple: to hold back the drops of rainwater and store it in a perfectly clean place. Ponds or small basins, *kund* or *kundi*, reservoirs or *tanka*, the names and forms may vary, the function remains unchanged: to immobilize and store for tomorrow the drops that have fallen today"[8].

The reservoirs in Jaipur are located at various points: on hill crests, on a slope between two steep hillsides, in valleys, in the depression leading to a lake or on the plain, and in different contexts: in forts, associated with temples, within gardens, in isolated wild places or in the heart of the city surrounded by buildings (Fig. 5).

On top of the Jaigarh Fort water is collected on the ridges around the fortified walls during the monsoon season. Loops have been built to encircle the ridge and retain rainwater. This 4km-long system is made up of three successive loops that enable to collect more water, control its flow speed and remove impurities through sedimentation. The first loop begins at the highest point of the hills, 4km south-west of the fort. An aqueduct connects it to the second loop at a slightly lower altitude, and so on to the third and final loop. This loop ends in a large, reinforced canal that carries all the water collected in the fort through an underground

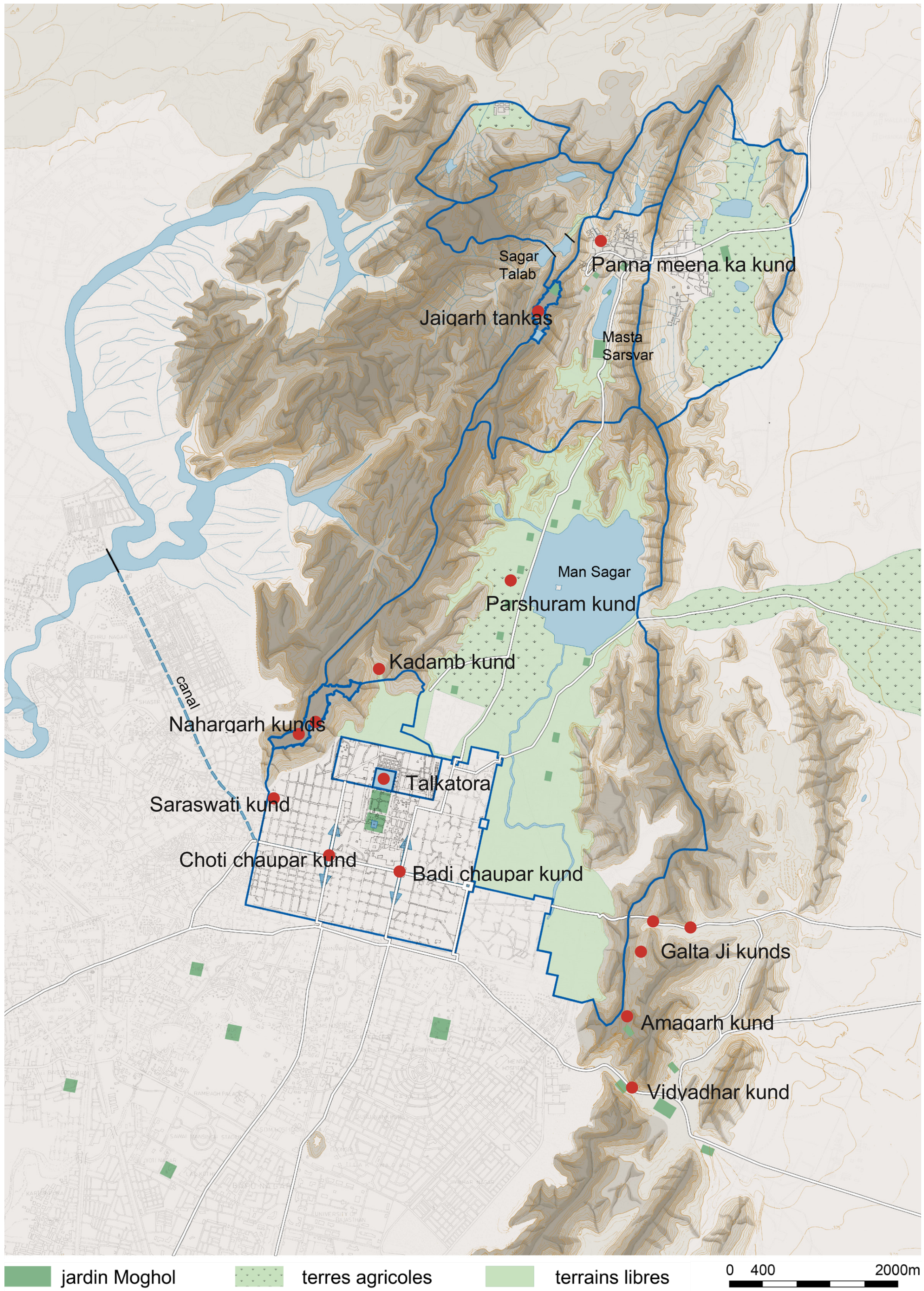

Fig. 5: The water system of Jaipur and localisation of reservoirs. (Source: Drawn by Claire Joulia based on A. Borie, F. Cataláa, R. Papillault, *Jaipur ville nouvelle du xviiie siècle au Rajasthan*, Paris, Thalia, 2007, p. 28)

tunnel equipped with a metal grate that allows the water to pass through the fortified wall, free of the heaviest sediment. Once inside the fort, the tunnel splits into two channels. One directs the first, less pure rainwater into the pit to water the animals, while the other takes the clean water to three tanks, called *tanka*[9]. These were used for domestic purposes by the royal family and the general public. While the tank in Jaigarh fort was covered the one designed at the Nahargarh fort is open to the sky. Morna Livingston describes it:

> “Because its pool was excavated and its irregular side walls shaped into stairs, Nahargarh resembles a quarry, almost an amphitheater around the water. Its well is designed so that monsoon water falling on the slopes is channeled through a shell-like spiral to feed its pool. As monsoon rains often carry a heavy burden of sediment, the twisting spiral encourages silt or stone to settle where it can easily be removed”[10]. (Fig. 6a and 6b).

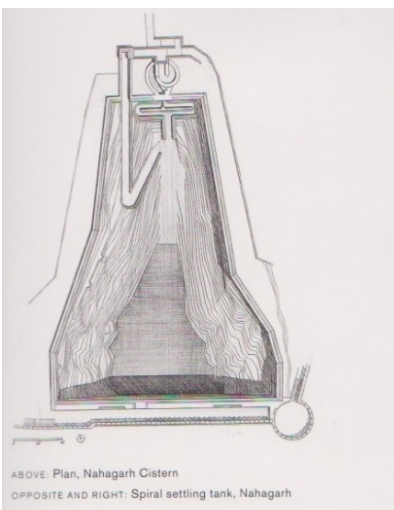

Fig. 6a: Nahargarh cistern, drawing Morna Livingston, *Steps to water: the ancient stepwells of India,* Princeton Architectural Presss, New York, 2002, p. 129
Fig. 6b: Nahargarh cistern, photography Savitri Jalais, 2018

Four reservoir- *kund* are situated at the heart of the city, like the Tal Katora reservoir, in a dense urban environment where the presence of water has a cooling effect in a city with an arid climate. A vast majority of them make the most of existing natural conditions that facilitate water harvesting. Some use the slope of a hill as a basin wall so as to simplify and reduce costs in construction. The reservoirs have certain common characteristics and present also a significant diversity in terms of their size (width, length, depth) and a great architectural diversity.

The differences can be extreme when the smallest reservoir, the Kadamb Kund of the Galta Ji complex, which measures fifteen meters wide, is compared to Tal Katora, the largest in the city, which measures two hundred and fifty meters on each side. This difference in dimensions can be seen with the depth of each reservoir: shallowest reservoir, the Saraswati Kund measures three meters deep, and the Surya Kund measures more than sixteen meters deep. These variations in size can be explained by different factors. First, water requirements can influence the size of the reservoir. Indeed, it is clear that the larger a tank, the greater its water capacity will be. This is for example the case for the tanks of Jaigarh Fort, which has the covered *tanka* with the largest storage capacity in the country. However, the morphology of the territory can also determine the size and depth of a reservoir, like for example the Surya Kund, which has an almost vertical natural slope of the hill constituting one of the walls of the reservoir (Fig. 7). Depending on the origin of the water, the morphology of the territory of establishment, the needs of the population, we observe various techniques for capturing and transporting water.

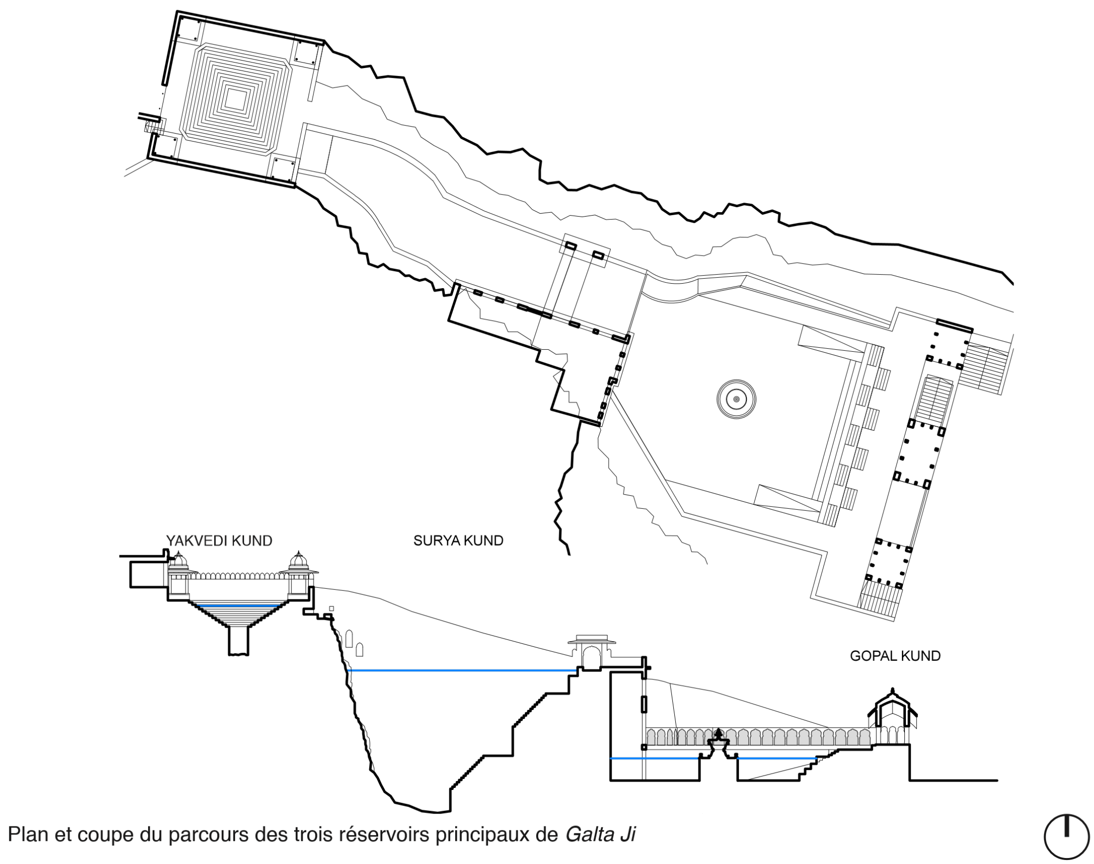

Fig. 7: Galataji temple and water complex, measure drawing Claire Joulia, 2018

Most of the reservoirs are surrounded by a wall whose height often varies from one to two meters. This wall is often pierced with one or more small openings connected to the channels which supply the water tank. It is generally also provided with one or more larger openings which serve as entrances for men or animals. This wall is built directly around the tank to protect the water it contains from impurities that could be carried inside by the wind.

"Water and humidity damage buildings to the point that, if they are not regularly maintained and repaired, they quickly fall into disrepair. While disused temples from the first centuries CE may survive in ruined rubble, the pits of neglected water structures fill with soil and waste and easily disappear underground»[11].

Today, even if some reservoirs have retained their former functions and uses, most are welcoming new ones or, on the contrary, are completely abandoned. Often the *kund* associated with temples and therefore having a religious and non-functional value have not undergone any modification of their functions and uses. Indeed, the Panna Menna ka Kund, the Yakvedi Kund, the Surya Kund and the Gopal Kund, are still used only for religious rituals such as ablutions or bathing of men and women. Some tanks are fortunate to have recently been restored and cleaned by different organizations, so that they can still perform their function properly. This was the case of the Panna Meena ka Kund in 2015, the Kadamb Kund in 2016, and the Vidyadarh Kund in 2019.

4. TODAYS HERITAGE IN CONTEMPORARY CONTEXT

Today, the city has a population of 3 million living in an area of 484.64 km^2, and forecasts predict that by 2035 it will have more than 6.5 million inhabitants. How can the expansion and densification of this city be planned in such a way as to consider the management of water, the environment, energy and transport, while at the same time respecting the specific historical character of the city and its traditions? At the time of its creation, numerous wells and basins, large reservoirs and water circuits were built across an entire territory to supply the city with water. With the introduction of a public water distribution network at the end of the 19th and beginning of the 20th centuries, this system was gradually abandoned, even though its architecture, often very imposing, persisted in the landscape (Fig. 8).

These water structures mark today the physical landscape of the city, they are often part of the city's animated public spaces, and their maintenance or revival may or may not be related to the original water use for which they were initially built. Some on the contrary are today not only abandoned but their historical geographies overlaid by urban developments that do not always consider their flows and patterns[12]. In this context, questioning their present role as vectors of nature in an urban context – the cooling effect of water, a haven of peace, gathering places and playgrounds – can be propitious in today's dense and polluted metropolis.

In face of Jaipur's rapid urbanization, its current population of 3,9 million inhabitants and the increasing demand for water, a new water system has not only replaced the old system but created the conditions for its extinction: pipes and channels draw water from sources that extend well beyond the city limits and water is currently supplied by the Bisalpur dam situated 120km south of Jaipur. The approach is utilitarian and to use the words of Fulton 2001[13], this new water management views water as a fuel for the urban "growth machine", tapping in the process the natural resources of other secondary towns and cities and transforming a whole territory into a desert. Furthermore, this water supply being insufficient, it is constantly supplemented by a large number of water pumps, which considerably deplete the ground water level. Gradually, an entire system is today abandoned while its architecture is still very much present in the Jaipur landscape, its water level reduced and greatly polluted.

Fig. 8: Talkatora lake within the extended, densely built city, photography Savitri Jalais, 2018

The study of the potentials of these historical water systems, often designed in a monumental scale, opens new perspectives. Can they be reclaimed, conserved, revitalized so as to form part of a local, equitable and sustainable approach to water, offering a significant quantity of water to the city, as well as public spaces? And most importantly, can these structures re-enter the cultural imagination and be part of a living heritage that fosters "a sense of culture as a capacity to aspire"?[14].

ACKNOWLEDGEMENTS

This article is part of the research programme « Jaipur 2035, Rainwater harvesting and metropolisation », 2017-2020, winner of *The eco-century project*, Fondation Braillard Architectes, Geneva. It is based on student workshops in Jaipur and memoirs written by Master students in architecture following the Seminar: Architecture - Heritage, theories and systems at the School of Architecture (ENSA) in Toulouse. I would like to particularly mention the mémoires of Claire Joulia, *Atlas des réservoirs de Jaipur et d'Amber, Analyse typologique des reservoirs*, 2019 and of Léonore Lagrange*, Atlas des Baolis de Jaipur et Amber, Étude du fonctionnement des Baolis.*

NOTES AND REFERENCES

1. Read Anupam Mishra's *Radiant Raindrops of Rajasthan*, translated by Ms. Maya Jani, Research Foundation for Science Technology and Ecology, 1995
2. Numerous books and articles have been published on the city of Jaipur, based on to the Vastushastras geometric framework of a mandala. The urban plan was based on a square formed Mandala, grid system with nine districts reserved for trade and crafts, separated by wide avenues intersecting at right angles.
3. Palaces built in the new city but also in Amber during Jai Singh II's first years in power were constructed in the Mughal style for the aristocracy and his court (Borie, 2007)
4. For further reading refer to Andreas Volwahsen, Cosmic architecture in India, The Astronomical Monuments of Maharaja Jai Singh II, Prestel-Mapin, 2001 and Raina Dhruv, "Circulation and Cosmopolitanism in 18th Century Jaipur. The Workshop of Jyotishis, Nujumi and Jesuit Astronomers" in C. Lefevre, I. Zupanov and J. Flores (dir.) *Cosmopolitismes en Asie du Sud, Sources, itinéraires, langues (XVI^e^-XVIII^e^ siècle)*, Purushartha 33, Paris, 2015
5. For example, in Benares, there was an extensive system of underground drains dating back to the 16th century, called Nawabi drains, intended mainly for rainwater. Rectangular in shape and irregularly inclined, they were made of rough bricks and stones (from 1 to 6 feet wide and 1 to 9 feet high), extended on different levels under the center of the paved roadway and were connected to the courtyards of the houses. See Savitri Jalais, *Les ghat de Bénarès. Variations architecturales d'une rive sacrée,* Genève, MétisPresses, 2022
6. See Rainfall profile of Jaipur: http://amssdelhi.gov.in/RESEARCH_FILES/JAIPUR_RF_PROFILE.pdf
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13. W. Fulton, *The Reluctant Metropolis: The Politics of Urban Growth in Los Angeles,* JHU Press, 2001.
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Volume 349
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ENVIRONMENTAL AND CLIMATE-RESPONSIVE URBANISM

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