A FRAMEWORK OF THERMAL SENSITIVE URBAN DESIGN BENCHMARKS: POTENTIATING THE LONGEVITY OF AUCKLAND'S PUBLIC REALM

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ABSTRACT

One of the key objectives of contemporary urban design is to ensure the quality and activity within urban public spaces. Presented as a progressively emerging paradigm in this process, the effects of urban climatology are increasingly elucidating the need for further climate responsive environments. Having the possibility to contribute to the quality of life within cities, there is a strong developing interest in the quality of urban public spaces due to their role in establishing microclimatic thermal comfort levels (Katzschner, 2006). Moreover, this interest is one that shall increase along with the progression of climate change effects upon outdoor environments.

Nevertheless, it is often that climatic assessments lack bottom-up climatic indicators, tools and practical benchmarks (Matzarakis and Amelung, 2008). As a result, this obstructs local decision making, and practices of localised adaptive design.

This paper is launched with the view that the sustainable development of a city primarily depends on the capacity of architects and urban designers to offer outdoor urban spaces with high environmental quality. In this scope, the multifaceted practice of microclimatic attenuation plays a fundamental role (Reiter and Herde, 2011).

Accordingly, these interdisciplinary professions are now challenged with overcoming the distinct fissure between climatic knowledge and physical application. In an effort to address such discrepancies, the paper launches a framework of international precedents of built and conceptual projects that address thermal comfort levels in public spaces. This organisation will be cross-referenced with theory that supports its structure and typological division.

With Auckland as the focal case study, the solutions that are extracted from the framework will be hypothetically scrutinised in terms of options for alleviating given events of increased temperature and heat waves within the city. In this way, microclimatic concerns are hence framed into an opportunity to potentiating the use, and longevity, of Auckland's public realm.

KEYWORDS:

Urban Design; Public Space; Thermal Comfort; Climate Change

1. INTRODUCTION

Before reaching the mid-twenty-first century milestone, it is expected that population, urban density and CO_2 emissions shall significantly increase in Auckland. Consequently, sustainable decision making becomes fundamental in amalgamation with the council's aim to make Auckland the world's most liveable city by 2040 (Auckland-Council, 2013). In conjugation with this expansion, the practice of urban design is also presented with the interdisciplinary challenge of preparing for impending local 'risk factors' as a result of climate change.

Although knowledge regarding outdoor thermal comfort has grown in recent years, its assimilation with climate responsive urban design has been considerably limited. As a result, local decision makers and designers often lack the design indicators and benchmarks to: (1) address existing microclimatic implications in public space design; and more prominently, (2) prepare for the invigoration of these respective insinuations as a result of climate change. With the aim of tackling such discrepancies, and through a Research for Design approach, this article reviews a range of international solutions that address similar microclimatic constrains to those found in Auckland. Additionally, and as part of an ongoing doctoral research, this exploration launches a demonstrative case study on how a framework of thermal sensitive urban design can launch new deliberations in both local policy and design guidelines for climate-responsive public space in the city.

2. NEW ZEALAND'S CLIMATE AND FUTURE IMPLICATIONS

As a means to identify a basis for climatic regionalisation and comprehend variables from Global Circulation Models (GCMs) outputs, the Köppen-Geiger (KG) climate classification system has classified New Zealand as a Temperate/Mesothermal climate. More specifically, and supported by a top-down outlook, the updated world map of the KG system classifies this genre of climate as 'Cfb', meaning a 'Maritime temperate climate' or 'Oceanic climate' (Peel, Finlayson and McMahon, 2007). Resultantly, this is concomitant with temperature fluctuations associated with large-scale climate patterns over the Southern Hemisphere and the Pacific Ocean. These meteorological phenomena have a temporal timeframe that can range from seasons to decades, such as the El Nino-Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO). Each of these oscillations can influence seasonal temperatures, wind patterns, and precipitation levels (MfE, 2008). Consequentially, this natural variability invariably blurs the superimposition with long term human-induced climate change trends.

Based on the disseminated figures from the National Institute of Water and Atmosphere research (NIWA), New Zealand does not have a broad temperature range, and it lacks extreme values that are commonly found in most continental climates. Moreover, and due to being located in the Southern Hemisphere, northern cities experience higher temperatures throughout the year. As shown in Table.1, Auckland is one of these cities and is one of the warmest city centres in New Zealand.

Table 1 – Summary climate information for the six main City Centres in New Zealand[1]

Location	**Mean Relative Humidity**	**Wet-days**	**Sunshine**	**Temperature**				**Wind Speed**
	% (9am*)	>= 1.0 mm	Hours	Mean °C	Mean Max °C	Mean Min °C	Hot Days (Max Temp.** > 25°C)	Av. Wind Speed m/s
Auckland	82.3*	137	2060	15.1	19.0	11.3	21	4.72
Tauranga	78.8	111	2260	14.5	19.1	10.4	21	4.44
Hamilton	85.0	129	2009	13.7	18.9	8.7	28	3.33
Wellington	82.3	123	2065	12.8	15.9	9.9	3	6.11

[1] * Average Relative Humidity levels were taken at 9am, hence these figures vary approximately if combined with afternoon RH levels – For the case of Auckland this would decrease annual RH approximately to 76%. ** Annual count of 'hot days' where temperatures exceeded 25°C – values presented are annual averages since mid-twentieth century. Wet-days, sunshine, temperature, wind speed, and average relative humidity data are mean values from the 1981-2010 period.

Christchurch	85.1	85	2100	12.1	17.2	7.3	21	4.17
Dunedin	73.1	124	1585	11.0	14.7	7.6	8	4.17

Source: Adapted from (National-Climate-Centre, 2013, Mackintosh, 2013a, Mackintosh, 2013b)

Due to being encircled by the Pacific Ocean, the country is expected to experience a delay in mean temperature change in comparison to global averages over the medium term (Gluckman, 2013). Notwithstanding, national climate change projections indicate 'very confidently' that until the end of the century there shall be: (1) a temperature increase of between 0.2-2.0°C by 2040, and between 0.7-5.1°C by 2090; (2) an increased frequency of high temperatures; and, (3) an accelerated rate of temperature increase in comparison to the temperature patterns recorded for the twentieth century (MfE, 2008).

At a regional scale, and returning to the case of Auckland, it is a projected that by 2100, there will be at least 40+ extra 'hot days' where maximum temperatures surpass 25°C (PMCSA, James Renwick, and NIWA in Gluckman, 2013). In retrospect with current values shown in Table 1, this implies that there will be a 200% increase in annual 'hot days'.

Furthermore, it is also worth noting that also due to the proximate 'ozone-hole', the county's peak Ultra Violet (UV) intensities can be 40% higher in comparison to similar latitudes in the northern hemisphere (e.g. the Mediterranean area). Although an UV index of 10 is already considered extreme, this index value can exceed 13 during the summer in cities such as Auckland.

In this light, perspectives towards the future adjoin the opportunity to deliberate upon more frequent and intense temperature levels in the city. Consequently, contemporary urban design embraces the need to certify that thermal comfort levels are addressed in the intricate balance between the urban microclimate, human characteristics, and the use of public spaces (Oliveira and Andrade, 2007). Regrettably, although the characteristics of urban climate have been well studied in the past two decades, there is little association with the possible application of physical urban design interventions.

In the case of Auckland, although it shall face more attenuated climatic effects in comparison to global averages, its Unitary Plan (UP) invariably recognises the need to "*increase the resilience of Auckland's communities and natural and physical resources to the anticipated effects of climate change such as (…) more frequent and extreme weather events*." (Auckland-Council, 2013, p.174). Moreover, and presented as a 'Quality urban growth objective' in the UP, there is also an ardent interest in a "*high quality network of public open spaces and recreation facilities that enhances quality of life (…) and contributes positively to Auckland's unique identity.*" (Auckland-Council, 2013, p.178). Given the recognition of future climatic implications, and the importance of Auckland's public spaces, urban resilience and adaptability becomes a fertile scope of opportunity for local action. In this way, local decision makers and designers are hence tasked with considering the long-term longevity of the city's public realm that shall determinedly face climatic hurdles until the end of the century.

3. URBAN DESIGN CASE STUDIES AND BENCHMARKS

Since the turn of the century, the maturing climate change adaptation agenda has gained a new weight, and has instigated local decision makers and designers to search for measures to address local 'risk factors' (Costa, 2011). This early, yet developing bottom-up perspective, is one that explores how urban design and climatic adaptation can tackle meteorological implications through an interdisciplinary approach.

This section explores existing bioclimatic case studies that can potentially be used as benchmarks to address the impending threat of increased temperatures and heatwaves upon Auckland's public realm.

In order to facilitate the typological differentiation between the discussed measures, and adapted from authors such as (Nikolopoulou, 2004, Erell, Pearlmutter and Williamson, 2011), four principal categories have been respectively established: (1) trees and vegetation; (2) shelter canopies; (3) materiality; and lastly, (4) water and vapour systems. Accordingly, existing practices are here viewed as an opportunity to shape new potential measures, and additionally launch new considerations in Auckland's local regulatory and non-regulatory, policy and design guidelines.

3.1 Trees and Vegetation

When considering the long term environmental adaptability of a city, it is consensus that vegetation can significantly contribute to the improvement of the urban microclimate due to its ability to reduce air temperature through direct shading[2], and evapotranspiration. More specifically, these processes induce the decrease of radiant temperature, influence wind patterns (both in velocity and direction), air regeneration (such as CO_2 absorption), and filter both dust particles and noise. Moreover, and besides these environmental attributes, vegetation can also provide additional psychological benefits to humans through aesthetic, emotional and physiological responses (Tsiros, 2010).

In existing studies relating to vegetation as a form of microclimatic control in urban open spaces, four principal green 'structures' can be identified: covering vegetation, isolated trees, groves or lines of trees (Picot, 2004). However, it is important to note that unlike inanimate devices, trees can change their dimension and degree of opacity during each season, and also during their lifetime. As a result, and although variations among trees may be considered aesthetically pleasing, the designer/planner needs to be aware of the shading pattern produced (Picot, 2004, Erell, Pearlmutter and Williamson, 2011). In terms of seasonal timeframes, there needs to be a consideration of: (1) how shade patterns can be provided in the summer when/where needed; (2) how solar penetration can be enticed during the winter period when/where needed; and, (3) which specific trees provide these desired effects during the pertinent time of year.

Regrettably, and although recognized as an effective way to alleviate higher temperatures, the incorporation of these vegetation reflections upon thermal sensitive urban design is limited. Yet, authors such as Shashua-Bar, Tsiros and Hoffman (2012) have explored the potential of passive cooling modelling design options on outdoor thermal comfort in urban streets in the shade of both trees and buildings. In their research, they analysed how street design scenarios benefited from the combination of vegetation with other measures in order to attenuate thermal comfort levels during the summer. To do so, the biometeorological index Physiologically Equivalent Temperature (PET) was used in order to assess levels in a typical street of Athens. Four theoretical design cases were undertaken: (1) increasing the trees canopy coverage area from its actual net level of 7.8% to 50%; (2) reducing traffic load from two lanes to one and thus approximately reducing 1500 vehicles down to 750 per hour; (3) increasing the albedo of the adjacent side walls from the measured 0.4 to 0.7 by implementing lighter colours; and lastly, (4) deepening the open space by increasing the aspect ratio (height/width proportions) from the existing 0.42 to 0.66 through elevating the side buildings by two additional floors (approx. 6m) (Shashua-Bar, Tsiros and Hoffman, 2012). The results of the study illustrated that the most successful passive design solution was that of increasing the vegetative canopy coverage that resulted in a decrease of 1.8K during noon hours. This is particularly interesting when comparing to the more drastic and expensive option of increasing the aspect ratio, which achieved a similar decrease of 1.9K.

Conversely, when applying this to Auckland, it is clear that due to its more temperate climate, considerations would need to be made upon the issue of overshading. Nevertheless, the constructed

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[2] Although there is still a limited amount of research regarding the direct effect of vegetative shading at pedestrian levels, the doctoral thesis of Ana Almeida suggests that *"trees, just like other green spaces inserted in edified areas can lower temperatures by approximately 3°C"* Almeida, A. L. B. (2006). O valor das árvores: árvores e floresta urbana de Lisboa. Doctoral thesis in Landscape Architecture, Instituto Superior de Agronomia

Parisian climate sensitive redevelopment-project, 'Place de la Republique' (also located in the KG classification of 'Cfb') can be used as a practical example of how these issues can be resolved (Case 1). Trevelo & Viger-Kohler Architects and Urbanists aimed at addressing the thermal comfort and Urban Heat Island (UHI) effect within the now largest pedestrian square in Paris. Today, an overall of 134 deciduous plane (*Platanacease*) trees and 18 deciduous honey locust (*Fabaceae*) trees encircle both the new perimeter and central area. Unlike the common segregation between vegetation and the thermal design of the public space, and in line with their environmental approach, the square is "*comfortable as a result of a strategy that is at once urban, landscaped and architectural*" (TVK, 2013, p.7). More specifically, this strategy consists of implementing measures that prevent the square from becoming a 'heat island', namely by: (1) increasing planting and creating a unit of vegetation to provide maximum mass effect; (2) allowing the sun to penetrate and position the pedestrian areas in the sunniest areas; (3) blocking the colder winter winds by thickening the vegetation in the north of the square; and just as importantly, (4) linking the presence of vegetation in order to consolidate usage dynamics in the square to suit prevailing conditions (TVK, 2013).

Returning to the specific case of Auckland (and furthermore considering the temporal timeframe of 2040), the city is challenged with considering the specific implications of how vegetation can be appropriately introduced in order attenuate thermal comfort levels. Furthermore, and considering the responses from agencies such as the Auckland Regional Public Health Service (ARPHS) to the UP, the effects of UHI need to be considered further, especially given the future increases of both urban density and climatological impacts (ARPHS, 2013).

Respectively, and strengthened by the case studies presented in this first section, it is suggested that future projects[3] must consider vegetative: (1) annual shading patterns; (2) change in dimension and degree of opacity; (3) contributions to decreasing the UHI effect; and lastly, (4) effects upon the activity threads, and usage of the urban realm in accordance with prevalent microclimatic conditions.

3.2 Shelter Canopies

When addressing canopies or roof structures in urban open spaces, the air temperature underneath the structure is predominantly affected by the existing solar exposure of the space. In turn, this directly relates upon the geometry of the structure, components, and the properties of its construction materials. The respective radiant temperature is interrelated to the temperature of the inner surface of the roof, which can be either lower or higher than the air temperature of the space underneath. Furthermore, the air velocity in the spaces underneath depends ultimately on the incoming wind/air patterns that are allowed to enter/penetrate the area.

In the case of Auckland's Central Business District (CBD), passive strategies to decrease solar radiation through shelter canopies are already present. Yet, and using Queen Street as an instance, most measures are only applied upon commercialised street sidewalks, and not within local open public spaces. With hindsight, civic spaces such as Aotea Square, Freyberg Square, and Queen Elizabeth Square are currently recognised by the UP as "*becoming increasingly important as Auckland's centres intensify and access to high-amenity open space is needed for residents*" (Auckland-Council, 2013, p.58). Perhaps due to the fear of overshading, these spaces do not accommodate passive structures that decrease and/or attenuate local solar exposure. Although this is beneficial during the winter months (i.e. June to August), there is limited shading that would otherwise entice the increased usage of these spaces during the summer. Interestingly, prominent

[3] As an example, this will be particularly relevant in 'Move 6' of the Auckland's Masterplan; that suggests an ecological 'Green Link Network' that shall insert a 'wave' of green vegetation to enhance the environmental sustainability at street level as part of the redesign of Victoria Street and adjacent open spaces Auckland-Council (2013). The Proposed Auckland Unitary Plan (notified 30 September 2013). PART 1 - Introduction and Strategic Direction. Auckland, New Zealand, Auckland Council .

studies in the use of New York's public spaces suggest that "*the days that bring out the peak crowds on plazas are not the sparkling sunny days with temperatures in the* [low 20°Cs] (…) *it is the hot, muggy days, sunny or overcast, the kind that could be expected to make people want to stay inside and be air conditioned, when you will find the peak numbers outside*" (Whyte, 1980, p. 44). Following this line of thought, the interplay of canopies regarding the provision of choice between experiencing sun, shade, or in-between areas becomes indispensable.

However, before any intervention can be considered, there needs to be a local and annual understanding of: (1) the patterns of existing solar radiation exposure (usually measured in hours); (2) the shadows that are cast from on-site elements (i.e. such as vegetation and amenities); (3) the shadows that are cast from off-site elements (i.e. such as contiguous structures and buildings); and, (4) existing encircling wind patterns[4].

Once established, thermal sensitive urban design can present the opportunity to improve the current thermal response of these spaces in both colder and hotter months. More prominently, the long term response to increased higher temperature and frequency in Auckland can be tackled through a precautious approach. In this scope, both permanent and temporary measures can be considered to increase local shading opportunities.

In the pursuit for case studies that have used shelter canopies in their bioclimatic approach to the public realm, permanent solutions can be extracted from the entries from the European competition 'Re-Think-Athens'. Although situated and tempered for a hotter climate (i.e. 'Csa' in the KG classification), many of the proposed measures can be adapted to Auckland's public realm and enclosing climate. The winning proposal 'One Step Beyond' (Case 2) by OKRA Landscape Architects based their design upon a pedestrian-orientated space that incorporated contemporary ideas of climate control in order to address thermal comfort through microclimatic attenuation (Knuijt, 2013). In one of the public spaces within the redevelopment proposal (Omonia square), a limited amount of shelter canopies were introduced into the space. Although the four canopy structures shade less than 10% of the total area of the public space, they are strategically placed on the extremities of the square alongside kiosks and food/beverage units. As a result, the risk of overshading during the winter is null, nonetheless, effective shading is still accomplished during the summer in strategic locations.

Another noteworthy and runner up entry was the submission of ABM Architects 'Activity Tree' that although shall inevitably remain as a concept, offers nevertheless valuable precedents in terms of shelter canopies (Case 3). Established through an in-depth site analysis, the zones which would require protection/attenuation from solar radiation were to be protected by 'Activity/Bioclimatic Trees'. These canopies would cast shadows in specific areas and would serve as an advanced bioclimatic device that would be able to capture energy and water[5]. Through a detailed analysis of sun patterns, and in order to permit solar penetration during the winter, the structural celosias system allowed the winter sun to penetrate the covered spaces.

Additionally, it is also worth noting that short term interventions also find their niche in this category of thermal responsive urban design. Here, design can also be interlinked with ephemeral projects in order to tackle periods of higher temperatures and/or heat waves in public spaces. As an example of an Ephemeral Thermal Comfort Solution (ETCS), Ecosistema Urbano Architects launched the conceptual project 'This is not an Umbrella' (Case 4). Although a simple concept, it is a lightweight and low cost solution which enables the climatic control of a large outdoor space. The proposal is

[4] Although the detailed techniques to calculate such issues surpasses the scope of this paper, it is worth noting that these calculations can be accomplished through the use of 3D modeling software that enable the investigation of local Sky View Factors (SVFs), and Computational Fluid Dynamics (CFD) for indicative wind speeds beneath the Urban Canopy Layer (UCL).

[5] For more information on the device visit: https://www.abmarquitectos.com/ingles/indexIngles.html

thought of as a citizen participation action that uses 1,500 hanging umbrellas to shade the patio of the Spanish Matadero Contemporary Art Centre. Lastly and also erected in the exterior of a contemporary Art Centre in New York, nArchitects built an ETCS to provide relief from the hot summer weather. With the use of a precise 3D model, the ‘Canopy’ was built with freshly cut green bamboo that provided armature for four different microclimates, which were also attenuated with three different water systems (Case 5).

Resultantly, both long-term and ETCS canopies find their role in attenuating urban thermal comfort levels. In the case of Auckland, this genre of intervention should be used to enhance availability of choice between exposed and shaded areas throughout the year. Moreover, the necessity of providing such choice shall increase along with the projected escalation of annual hot days in light of climate change. However, in order to avoid overshading the city’s public realm, careful analysis of existing solar patterns, shadows, and wind configurations is required. As demonstrated in the cases disclosed in this section, tempering of thermal comfort levels can only be accomplished through the understanding of local annual microclimatic implications.

3.3 Materiality

The phenomenon of UHI effects are becoming increasingly more intense in cities, and are consequentially coercing modifications in the urban microclimate. Apart from the risk of inducing thermal discomfort, increased air temperatures also can originate energy efficiency concerns due to increased energy consumption and inflated running costs (Santamouris, Papanikolaou et al., 2001).

Nevertheless, the thermal properties of the materials within the urban environment are amongst the most prominent factors in terms of influencing the UHI effect. With regards to the public realm, the presence of dark coloured surfaces in pavements result in the diurnal absorption of solar radiation, which is then released in the form of heat during the night. Accordingly, the use of high albedo urban surfaces can be an inexpensive measure that can potentially reduce summer time temperatures. In a study conducted by Synnefa, Santamouris and Livada (2006), it was concluded that, in general, the higher the reflectance and emissivity of material and/or coating, the cooler the surface remained. Accordingly, materiality also finds its niche in potentially attenuating urban surface temperatures within the public realm.

On reflection, the Parisian redevelopment La Place de Republic (Case 1) is a clear demonstration of how materiality can be directly used to address the UHI effect. More specifically, the local UHI effect was used as a design generator to reconfigure the area’s surface materials, whereby: (1) the shady zones of the square were paved predominantly in darker colours; and, (2) the open spaces were paved predominantly with generally paler colours. Similarly, the ‘One Step Beyond’ project (Case 2) also state in their proposal that “*the benefit of using cool materials such as light asphalt, light concrete or light natural stones, is their high reflectivity and albedo. Cool materials guarantee less absorption of radiation and lower surface temperatures compared to other conventional materials. Through this reduction of heat storage in urban materials, the process of cooling down ambient air temperature at night accelerates, which moreover implies reduction of energy demand by air-conditioning at night*” (Knuijt, 2013, p.14).

In the long term and when considering the implications of UHI effects in Auckland, it is essential to ruminate that the city is expected to grow by one million inhabitants by 2040. Naturally, the increased urban density in juxtaposition with increased temperatures will lead to the effects of UHIs becoming an increasingly pressing issue for local thermal urban design. As demonstrated in existing theoretical and practical knowledge, materiality can play an effective, yet economical, way of tackling such challenges. Moreover, and considering that most of Auckland’s CBD has an extensive amount of dark pavements, the deliberation upon urban surface albedo becomes a key issue in order to reduce surface temperatures during the summer.

3.4 Water and Vapour Mechanisms

This article has hitherto discussed the influences of vegetation, shelter canopies, and materiality upon thermal sensitive urban design. This section shall discuss the opportunities presented by water/vapour systems and shall examine their possible application in Auckland's public realm.

Previously, the presence of water and misting systems were customarily focused upon aesthetic and sculptural purposes in public space design. More recently however, there has been a considerably greater emphasis upon their interconnection with bioclimatic comfort in outdoor spaces in terms of adaptation efforts to climatic conditions (Nunes, Zolio et al., 2013). As a result, water and misting systems have taken on a new meaning in public space design.

Awarded the first prize in a local competition to re-develop the Khan Antoun Bey Square in Beirut, PROAP Landscape Architects (Case 6) explored a conceptual solution to improve outdoor thermal comfort standards. The dominant bioclimatic measure used in this project was a misting system, which in combination with vegetation, canopies and materiality, tackled hot-humid summers, and high solar radiation rates. This launched a deeper research into the effectiveness of temperature control systems in outdoor spaces by inducing evaporation through misting systems. The research concluded that misting-cooling systems can be complex, and its associated equilibrium with encircling air humidity is fundamental. In warm-humid summer climates, such as that of Auckland, water spraying and evaporation are more complex due to the existing amount of water already present in the atmosphere beneath the UCL. Subsequently, water pressure, nozzle types, and functioning periods become crucial in forming the correct droplets with the adequate amount of temporal intervals (Ishii, Tsujimoto and Yamanishi, 2008).

Following this line of reasoning a little further, although smaller Sauter Mean Diameters (SMDs) may lead to faster evaporation; larger SMDs can lead to more effective cooling, though at the expense of prospectively wetting surrounding surfaces (Alvarez, Rodriguez and Martin, 1991). So far, results presented by Japanese CFD studies have shown that there is no significant difference in temperature reduction for different SMD sizes, yet larger water particles (≈ 32.6 μm) remain longer in the air (Yamada, Yoon et al., 2008). Notwithstanding, Yamada, Okumiya et al. (2006) undertook a field experiment in Japan to explore the actual effects of sprayed micro droplets under a canopy in an urban open space. With the objective of decreasing both local air temperature and UHI effects, the results of the test showed that a total reduction of 3K was accomplishable.

These studies illustrate that although Japan has relatively high humidity levels, lower evaporation rates still do not impede the application of misting systems to cool down temperatures and attenuate UHI effects. Moreover, studies by Farnham, Nakao et al. (2011) showed that surface wetting can be practically eliminated by elevating the height at which the misting nozzles are installed in semi open spaces[6].

Earlier, and within the European context, developed by an interdisciplinary group led by the department of Energy Engineering and Fluid Mechanics from the College of Industrial Engineering of Seville, the Expo of 1992 in Seville (Case 7) was approached as a method to synthesis bioclimatic techniques with public space design. The various new techniques that were tested and installed concentrated on misting systems and bodies of water, namely the: (1) continuous blowing of air through a fan that was permanently kept moist; (2) installation of 'micro' water nozzles in tree

[6] In this particular experiment, a total of cooling of 0.7K was observed without wetting adjacent surface temperatures. This was accomplished by single nozzles spraying mists with a SMD of 41 – 45 μm, moreover, the resultant increase of encircling humidity had little or no effect on the thermal comfort as demonstrated by the identified Effective Temperature (ET). However, mists with greater SMD will cause surface wetting even from heights of 25m and is hence not suggested for cooling urban pedestrian spaces. Farnham, C., M. Nakao, M. Nishioka, M. Nabeshima and T. Mizuno (2011). "Study of mist-cooling for semi-enclosed spaces in Osaka, Japan." Journal of Urban Environmental Pollution 2010 **4**.

branches that created droplets with an average SMD of around 20.0 μm, where colder air then flowed downward, hence cooling the shaded areas; (3) 'sheets' of water in the form of ponds and waterfalls that cooled the spaces through evaporative cooling and strategically placed irrigation outlets (Velazquez, Alvarez and Guerra, 1992). Integrated with vegetation, canopies, and materiality, the public realm of the Expo was divided into three different types of spaces: (1) "Passage Areas" – with the prime functionality of supporting the main flow of pedestrians, with an expected 'use timeframe' of below 15 minutes; (2) "Rest/Stay Areas" – with the primary goal of offering places for resting, eating, and social congregation, with an expected 'use timeframe' of over 15 minutes; and lastly, (3) "Adjacent Areas" – that were spaces of interconnectivity between the former. This theoretical division between Passage, Rest, and Adjacent areas aided thermal comfort design to be divided into medium level, high level, and low level thermal conditioning respectively.

Although Velazquez, Alvarez and Guerra (1992) argue that surface wetting leads to resource wastage, a more recent misting technique built into a French square can be explored to counteract such results. Also situated in a 'Cfb' climate, the project Le Miroir d'Eau (Case 8) by Michel Corajoud, Pierre Ganger, and Jean-Max Llorca initially aimed at reintroducing vegetation into the space in order to attenuate the local microclimate. However, and based on the concept of addressing thermal comfort levels and reflecting surrounding facades, the 'water mirror', and an incorporated on-site fog system (also based on a 'micro' nozzle system) were installed. In order to avoid algae and water wastage, the water which temporarily floods the square recedes back into the slabs after a few minutes, leaving the surface dry like in any other square. Grooves were installed in-between the granite slabs, to allow the water to be recollected, and re-prepared for the next induced 'flood'. In this way, wet surfaces become part of the design of the system which increases the climatic responsiveness of the once thermally problematic public space.

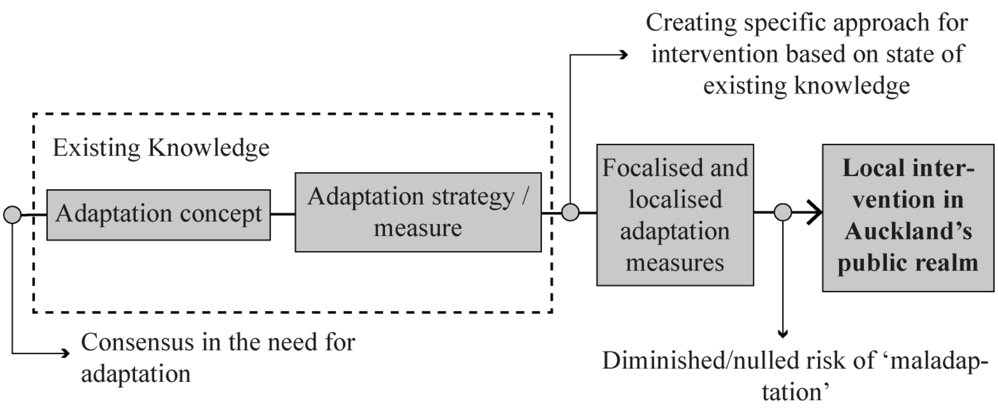
Returning to the ephemeral perspective, and as already discussed through the 'Canopy' project (Case 5), misting systems and water bodies have also been translated into ETCSs within the public realm. In this scope, one can also refer to the 'CoolStop' project (Case 9) by Chat Travieso Design, which in collaboration with the NYC Department of Transportation, designed a temporary misting system during an annual event that pedestrianized seven miles of the city's streets. Constructed out of PVC piping, and operated through a hydrant unit, the misting system cooled the microclimate during the summer heat in New York's public spaces.

Accordingly, and referring back to Table 1, Auckland's relatively high humidity levels need to be carefully deliberated when considering the application of water and misting mechanisms. As identified by Yamada, Yoon et al. (2008), such mechanisms tend to be more intricate in attenuating thermal comfort levels when the relative humidity surpasses the 70% mark. Nonetheless, this does not infer their inapplicability. Instead, three approaches can aid their applicability in Auckland's public realm, whereby: (1) surface wetting is undesired - requiring careful consideration of necessary water pressure, nozzle type, altitude, and functioning period/intervals; (2) surface wetting is permitted and water is reused within the system - requiring hence water runoff deliberation; (3) ETCS are installed as a temporary measure during the summer period. Even so, it is still necessary in all approaches that local microclimatic factors are considered in order to fully exploit the potentiality of such measures in attenuating thermal comfort levels.

4. FRAMEWORK ILLUSTRATION AND DISCUSSION

As aforementioned, climate change adaptation has grown exponentially within both the global scientific and political arenas. Accordingly, one can witness the increasing global ambition amongst decision makers and designers to diminish the gap between theory and action with regards to local adaptation measures (Nouri and Matos Silva, 2013). As shown in Figure 1, in order to introduce effective local climatic measures in Auckland's public realm without the risk of ineffectual adaptation (i.e. maladaptation), local agents must focalise their adaptation endeavours around specific local risk factors through a bottom-up attitude. In this way, existing knowledge within the adaptation agenda must subsequently be refined into an appropriate response through a ‘case by case’ attitude. All the same, the gap between theory and action with regards to thermal comfort attenuation is extensive, leading to a lack of precedential benchmarks, indicators, and examples that could otherwise aid local decision making and design. Having Auckland as the central case study, Table 2 demonstrates the bioclimatic case studies from the international arena that address similar microclimatic constraints that are already, or shall soon be, witnessed in the city.

Figure 1 – Proposing adaptation measures which focalise upon Auckland’s public realm and local risk factors.



Source: Adapted from (Nouri and Matos Silva, 2013, Proceedings presentation slide)

Table 2 – Framework of relevant bioclimatic case studies within the international arena

N	Project Title	Status	Location	Categorical Division	KG Climate Classification	Temporal Scope
Case 1	‘Place de la Republique’ Re-Dev.	Cons. (2013)	Paris	Trees/Vegetation Materiality Water/Vapour	‘Cfb’	Long-Term
Case 2	‘One Step Beyond’	Under Cons. (2013-2015)	Athens	Trees/Vegetation Shelter/Canopies Materiality Water/Vapour	‘Csa’	Long-Term
Case 3	‘Activity Tree’	Conceptual (2013)	Athens	Trees/Vegetation Shelter/Canopies Materiality	‘Csa’	Long-Term
Case 4	‘This is not an Umbrella’	Conceptual (2008)	Madrid	Shelter/Canopies	‘Csa’	ETCS
Case 5	‘Canopy’	Cons. (2004)	New York	Shelter/Canopies Water/Vapour	‘Cfa’	ETCS
Case 6	Khan Antoun Bey Square	Conceptual (2010)	Beirut	Trees/Vegetation Water/Vapour	‘Csa’	Long-Term
Case 7	Expo’92 Seville	Cons. (1992)	Seville	Trees/Vegetation Shelter/Canopies Materiality Water/Vapour	‘Csa’	Short-Term
Case 8	‘Le Miroir d’Eau’	Cons. (2006)	Bordeaux	Water/Vapour	‘Cfb’	Long-Term

Case 9	'CoolStop'	Tested Prot. (2013)	New York	Water/Vapour	'Cfa'	ETCS

Although some of the case studies were indeed based on warmer climates, they nevertheless suggest very pertinent benchmarks that can be adapted to New Zealand's more temperate climate. As discussed in the different sections of this article, these revisions can straightforwardly be undertaken by considering the microclimatic implications encircling Auckland's public realm. In this way, documents such as the regulatory UP, and non-regulatory Auckland's Design Manual (ADM), can introduce more concrete guidelines on how public spaces could be made more responsive in light of increased hot days, heat waves and managing UHI effects.

More specifically, and now considering the ADM's 'Section 4 – Design for Comfort and Safety', the presented framework launches existing applicable bioclimatic case studies that suggest efficient means to: (i) maximise the effects of local evapotranspiration in areas increasingly prone to UHI; (ii) effectively reduce/enable solar penetration and wind patterns; (iii) design suitable annual availability of choice between exposed, semi-shaded, and shaded areas (iv) support and consolidating urban activity threads through passive strategies and flora; (v) reduce surface temperatures through the implementation of cool materials; and, (vi) install misting systems that induce (or not) surface wetting in order to attenuate local thermal comfort levels. In this light, the local design manual could hence form the basis for future action in Auckland's public spaces, which shall very likely require investigations into their: (i) use of passive strategies and/or vegetation to attenuate the effects caused by the increase of annual hot days; (ii) overcoming of difficulties presented by high relative humidity levels when cooling the public realm; and, (iii) decreasing urban surface temperatures by rethinking the extensive use of dark pavements through the introduction of cool surfaces and materials.

CONCLUSION

As with most sectors in the maturing climate change adaptation agenda, there is considerable theory, yet limited practical benchmarks that can directly aid local decision making and design. Nevertheless, this article has argued that there is sufficient existing knowledge to respond to the growing need for thermal comfort attenuation in Auckland. Moreover, and although New Zealand shall witness more attenuated climate change over the next few decades, the discussed existing national projections nevertheless indicate that adaptation is still essential. On top of these meteorological projections, the considerable increase in population, urban density and CO_2 emissions until 2040 augments such needs even further. To address such requirements, the presented framework of bioclimatic case studies has demonstrated a range of benchmarks that were developed by cities facing similar microclimatic issues to those that are present or expected in Auckland. As a result, existing guidelines such as those pertaining to the city's public realm's comfort and safety can hence be developed further in order to aid local designers and decision makers to learn from existing approaches, and more importantly, to launch their own focalised approach. In this way, thermal sensitive urban design is launched into a fertile arena that's application in a world of climate change, is required in building a better New Zealand.

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