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MAPPING "WIND COMFORT" IN PUBLIC URBAN SPACES OF GALLE FORT, SRI LANKA

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Abstract
With a focus on public urban spaces, appropriate design could enrich the quality of urban life. These spaces should be comfortable and safe enough to invite people to stay outdoors, unhindered by numerous impacts of the microclimate, like excess wind. This research maps the influence of local wind behaviour on the users in public spaces of Galle Fort, Sri Lanka - a UNESCO World Heritage Site. The microclimatic context of the Galle Fort is modelled by means of computational simulation utilising the software ENVI-met, with a focus on generating data on dominant wind velocities and wind directions in the study area. Selected urban plots are mapped to identify; discomfort zones created by wind velocities exceeding threshold values. The study is limited to selected simple activity typologies and utilise the thermal comfort indices Predicted Mean Vote to communicate results. The results show that uncomfortable velocities occur at building corners, streets, squares and on the Fort rampart, high enough to disturb activities associated with the sitting position in the South, Southwest, and West wind directions. Conclusions draw on the need for wind assessment in public spaces for comfort and the importance of establishing a holistic approach towards the wind comfort environment.

Keywords: *Wind Comfort, Wind Mapping, Microclimate, ENVI-met, Galle Fort*

1. Introduction

"...Public spaces are the primary site of public culture; they are a window into the city's soul" Zukin, (1995)

Public spaces enrich social contact between the city inhabitants by accommodating various recreational or cultural related activities. Successful public spaces are not merely transitional spaces to walk through. They should invite people to slow down from their daily routines, contemplate and experience the place. This almost completely depends on the design of the public space in terms of aesthetics, accessibility, comfort, safety and diversity. "Urban design determines the quality of urban life that is related to physical and climatic ambiance but also to social aspects." (Szucs, 2013).
In an accelerated development and urban growth scenario, the need is to encourage more people to use outdoor public spaces frequently. Signifying a change in planning attitude, Sri Lanka's development plans suggest more recreational urban spaces to promote social contact and good-will, thus, uplifting quality of urban life, while fulfilling cultural and economic, goals and objectives. The question arises if these spaces are adequately comfortable and thus conducive as places for staying, by design.

Outdoor thermal comfort is a key contributor for successful urban public spaces. The urban morphology of the built environment around public spaces has a direct influence on the microclimate. Of the parameters that drive the level of thermal comfort, wind - expressed as wind direction and wind velocity - is a crucial component. The study is a research initiative focused on the investigation of the wind environment, and therefore 'wind comfort', in urban public spaces.

Galle Fort - a UNESCO world heritage site - a vibrant, living city that has become a 'need to visit' destination for any overseas traveller to the island, is selected. With its Dutch Colonial architecture and grid patterned streets, The Fort encompasses several public spaces which are worth of study and important to the overall ambience of setting.
Galle Fort is undergoing tremendous transformation mainly due to growth of the tourism industry, although regulation dictates that 35% of any development has to be maintained as residential. The main

element that drives the Galle's climate is generally the proximity to the Indian Ocean. The intensification of the wind velocities is common near the coast, therefore it is evident that an in-depth understanding of the wind characteristics of the Galle Fort is essential for design interventions facilitating outdoor urban living.

The primary objective of the study is to map the characteristics of the wind environment in relation to

Figure 29: Activity mapping of Galle Fort and key Public Spaces identified

the urban built fabric of the Galle Fort, with a particular focus on the public spaces. A computer simulation based research methodology is adopted to generate isocontour maps signifying thermal comfort and wind velocity. The analysis of these maps will discuss the quality of selected urban public spaces identified by the mapping, in relation to the built morphology and wind environment, for three simulation cases of varying wind directions. The primary outcome of the mapping is envisioned to generate a discussion on the 'wind comfort' - for specific tasks - of these public spaces.

The scope of study is limited to three identified wind directions prevalent in the context and the simulation is conducted for one particular day in June 2017, given the limitations of the software. The use of public spaces in the Fort is limited to the day time, therefore, the findings discussed are for the day time hours only.

2. Background

2.1 THE CONCEPT OF COMFORT

2.1.1 Wind Comfort

Gandemer (1978) describes that the changing behaviour of the wind and wind speed considerably effects the human body which occupies a space. The effects are divided into two main factors;

- The physical comfort of human body-referred to the forces induced by the variation of the wind with time and space, mechanically enforced on a human body, as an obstacle disturbing his or her preforming activity.(e.g. -hindering movements or disarraying clothing / hair)
- Thermal comfort of the human body - disturbance on the physiological heat exchange between the human body and the ambient space.

Acceptable wind comfort around and between buildings plays a prominent role. In general, the term, "wind comfort" questions the life quality in the public urban spaces. The assessment should focus on utilisation of the public spaces or building with, how the urban planning serves in respect to the wind comfort which people will experience. Most of these assessments done in the outdoor urban situations covered the people's experiences while preforming their most frequent activities. . (Koss, 2006)

Following this concept, the American Society of Civil Engineers (ASCE, 2003) describes these effects as mechanical direct effect of the wind force and thermal and indirect effects of thermal perception in combination with other climatic parameters. These two concepts will always be subjective to each. Conditions such as the type of activity, the climatic season, metrological conditions, and condition of the user - physically and / or mentally. All these aspects need to consider when assessment. (Table 1)

Table 1- ASCE, (2003) wind velocity threshold values for Wind Comfort		
Activity	:	Comfortable ranges (m/s)
Sitting	:	0 to 2.6
Standing	:	0 to 3.9
Walking	:	0 to 5.4
Uncomfortable for any activity	:	> than 5.4m/s

2.1.2 Thermal Comfort

For this study, the Predicted Mean Vote (PMV) model by Fanger in (1972) is adopted. Developed as a heat-balance model for the calculation of the (PMV) Predicted Mean Vote, which become a frame work for the establishing indoor thermal comfort. It is seen as most suitable for simple radiation conditions. Later, developed for the outdoor complex outdoor radiation conditions by Jendritzky et al. (1979, 1990). The PMV value is used to quantify the degree of discomfort to evaluate the predicted mean vote of a large quantity of people according to the scale below. (see Table 2)

Table 2: PMV Scale thermal sensation and physiological stress level		
-3.5	Very Cold	Extreme cold stress
-2.5	Cold	Strong cold stress
-1.5	cool	Moderate cold stress
-0.5	Slightly cool	Slight cold stress
0	Comfortable	No thermal stress
+0.5	Slightly warm	Slight heat stress
+1.5	Warm	Moderate heat stress
+2.5	Hot	Strong heat stress
+3.5	Very hot	Extreme heat stress

Matzarakis and Mayer (1997) used this model for developing PMV maps according to the annual and monthly averages in Greece to identify the period of strong heat stress exists. The study discussed fluctuating thermal conditions at individual case studies by using calculating PMV for selected grid area. Mapping PMV Provides comprehensive information of Bioclimatic heat stress on urban spaces. Also, the spatial distribution of PMV gives clear indication the thermal discomfort or comfort with respect the morphology of the existing urban context.

2.2 WIND FLOW AROUND BUILDINGS -

Wind flow regime presented by Oke, (1978, 1987) (Figure 2) state, wind characteristics between buildings change according to the geometry of the building array. Three types were identified; Wind flow is isolated when the spaces between buildings becomes wide; Flow interacts with wake circulation stream at intermediate spacing on the canyon; Flow interacts with skimming effect when the space becomes closer to each other.

Flow patterns show, (Figure 2) how the faster moving air at the top of the buildings deflects down to the ground. This phenomenon could create complex wind circulation in-between the building spaces, especially in building canyons.

2.2.1 Thermal Effects between buildings at pedestrian level

Wind contributes to define thermal condition of the microclimate near buildings at pedestrian levels. Thermal effects between buildings are influenced by the wind flow characteristics as follows (Offerle et al., 2007);

Warming at the leeward face of the building. - Due to the vertex created, the wake effect warms the leeward face, the air can also gain heat due to the buoyancy. More ejection of the canyon air could create more warming effects near the leeward wall.

Warming at the windward face of the building. - In this case the buoyance flow could divided in to two rotating vertexes. Offerle et al., (2007) shows that when the windward face warms up, heat fluxes are enhanced, due to the buoyancy with vertex circulation. Warm air flow from the roof level could change the thermal conditions of the area near the windward face of the building.

Warming at the surface between buildings - in this case the buoyance flow divides, similar to preceding case, but advection vertex circulates close to the top of the building because of the buoyancy. The heat effects between buildings are not only subjective to the wind, but also other conditions such as solar radiation, building energy exchange between indoor and outdoor, and anthropogenic heat fluxes.

3. Method

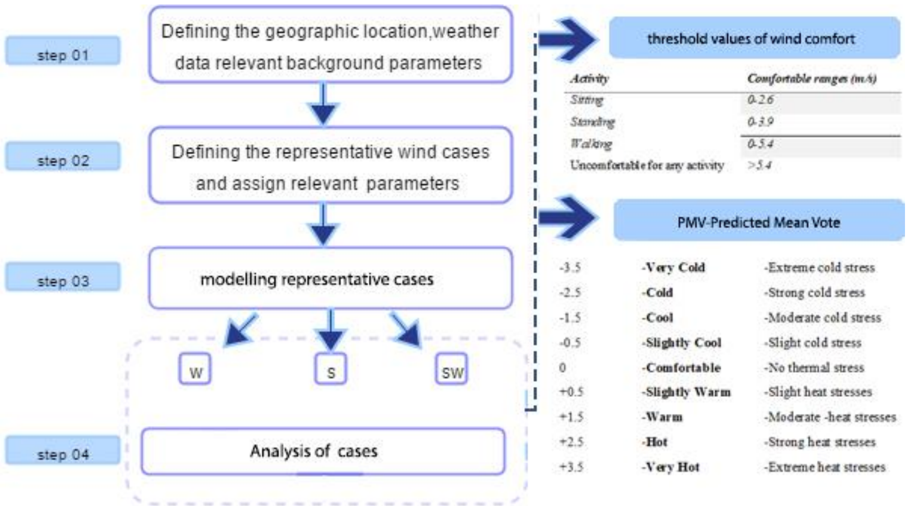


Figure 3: Research Design

Figure 3 defines the research design adopted. As detailed the study is conducted in four distinct steps, each establishing the data for the next.

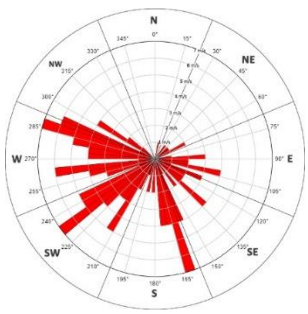
3.1 STEP 01 - DEFINING THE GEOGRAPHIC LOCATION, URBAN MORPHOLOGY AND WEATHER DATA

Weather Data - The primary objective is to establish the climatic and wind context of Galle Fort. Data collected from the Meteorological Weather Station within the Fort is utilised, for a period spanning from 1993 to 2016.

On site Survey - A field survey carried out at the context established activity patterns together with the types of activity the users of the public space engaged in. These form the activity types - sitting, standing, walking - the ultimate analysis would adopt to in the determination of wind comfort Detailed maps and on-site verification established the morphological metadata of the urban context.

3.2 STEP 02 - DEFINING THE REPRESENTATIVE WIND CASES AND ASSIGN RELEVANT PARAMETERS

This step is used to analyse and synthesise the collected data and formulate simulation scenarios. The data was collated to establish mean velocities and percentage of frequency for the primary wind



Wind Direction	Percentage of Frequency (%)
N	0.69
NE	4.17
E	9.72
SE	10.42
S	16.67
SW	24.31
W	25.69
NW	8.33

Figure 4: Wind Rose for Galle Fort with the percentage of frequency in terms of direction

directions. (see Figure 4.). The data shows Wind Speed in 10 m above ground, the mean wind velocities recorded the highest values in June, May, July months. However, the month of May is chosen as the focus for the study, given the corresponding field work period for the study. Thus, a mean wind velocity 5.64m/s is established, at 10m above ground as standard for the comparative simulations. Further, as shown in Figure 4 three main wind directions (as a study limitation) are taken as comparative simulation cases. The cases encompass the wind directions S, SW, and W.

3.3 STEP 03 - MODELLING REPRESENTATIVE CASES

The computer simulation software ENVI-met 4.0 is utilised to model the defined scenarios. ENVI-met is “able to simulate microscale interactions between urban surfaces, vegetation and the atmosphere. It allows analysing and apprehending the impact of small scale changes in urban design and landscape (for example: tree plantation, insertion of new buildings, replacement of mineral surfaces by vegetal ones etc.) on the microclimate (Bruse and Fleer, 1998). According to the available scientific literature, ENVI-met gives an adequate estimation of wind velocity, compared to observation and can be regarded as a valid tool for studying tendencies in airflow characteristics” (De Maerschalck et al., 2010).

3.4 STEP 04 - ANALYSIS OF CASES

The Analysis protocol utilises the ENVI-met extension LEONARDO 2014 for presentation and visualization of the simulated data in graphs and isocontour maps.
A critical focus of the study is wind comfort, therefore analysis protocol adopts the standards defined by the ASCE for simple activities and corresponding threshold wind velocities for wind comfort. (see Table 1)

4. Results and Analysis

Results and analysis encompass two identified public spaces based on the activity zone mapping. (see Figure 1). The data presented is for wind and thermal comfort characteristics at heights 1.5m, 3.5m, and 4.5m - to ascertain the effect of the Fort Rampart - and within a time period between 9.00am and 10.00am, June 2017. The isocontour maps generated by the simulation demonstrate the wind velocity changes within the urban fabric for South, Southwest and West wind directions, and at the heights defined, (see Figure 5, 6), while Figure 7 shows the Predicted Mean Vote (PMV) differences experienced.

4.1 URBAN FABRIC MORPHOLOGY AND WIND VELOCITY

Site A - Analysis clearly demonstrates the wind shadow effect of the Fort Rampart (the Rampart is 2.5m

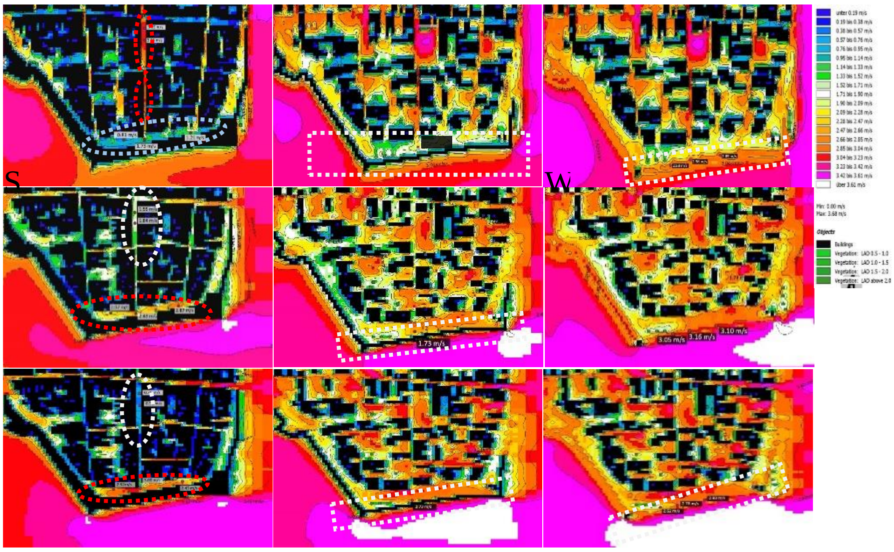


Figure 5: Site A - Wind velocity at 1.5m, 3.5m, and 4.5m for S, SW, and W wind directions

high from street level), where at 1.5m level the adjacent Rampart Road shows relatively low wind velocities, for all wind directions. This effect is negated once the analysis turns to the higher levels. The

Church Road is significant - especially when the wind is from the South. The perpendicular street to the Rampart measures a distinctively high velocity at 1.5m level, although not at the higher levels.

The Southwest and West directional winds paint a different picture, where the effect of the Rampart is not as significant and the overall patterns of velocity is enhanced throughout. Yet, the effect along Church Street remains distinct.

At the Rampart level, with the relatively undisturbed wind flow from the wind directions, created a highly ventilated zone.

Site B - In this zone two significant spaces in relation to the wind environment are highlighted. The Court Square, is an easily recognisable and prominent public space in the Fort. (Receptor points L and K). The effect of street orientation on the wind velocity is clearly demonstrated by the relative intensity of the South case. With a street pattern that runs North-South and East-West, culminate at the square, with well-defined edges, creating significant impact in wind velocity. Although diminished, in the two

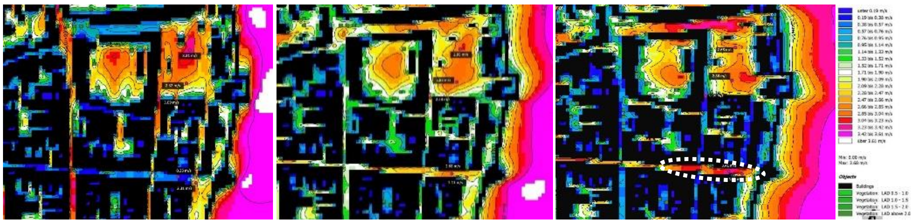


Figure 6: Site B - Wind velocity at 1.5m - S, SW, and W (from left to right)

other cases, the square remains significant because of the wind paths the streets create. The two open spaces with large trees, fed by narrow streets enhance these possibilities.

4.2 THERMAL COMFORT AND WIND VELOCITY

The PMV in urban public spaces that were identified in the wind velocity mapping is depicted as graphs. The graphs shown in Figure 7 demonstrate the PMV changes in the day time hours and compare for the changing wind directions. For all cases the environment is seen to be warm, albeit in varying degrees.
On the Rampart (Receptor Point G), a key public space, the changing wind has little or no effect on comfort. This is as opposed to Receptor point A immediately adjacent to the rampart. The wind shadow seen in the velocity mapping is evident with the thermal comfort values being warmer for the South wind direction. The clear correlation between wind velocity and thermal comfort is again demonstrated in the case of receptor point D, where and increased velocity is depicted as more thermally comfortable. At the Court Square with little variation of velocity with changing wind directions, the thermal comfort readings remains unvaried.

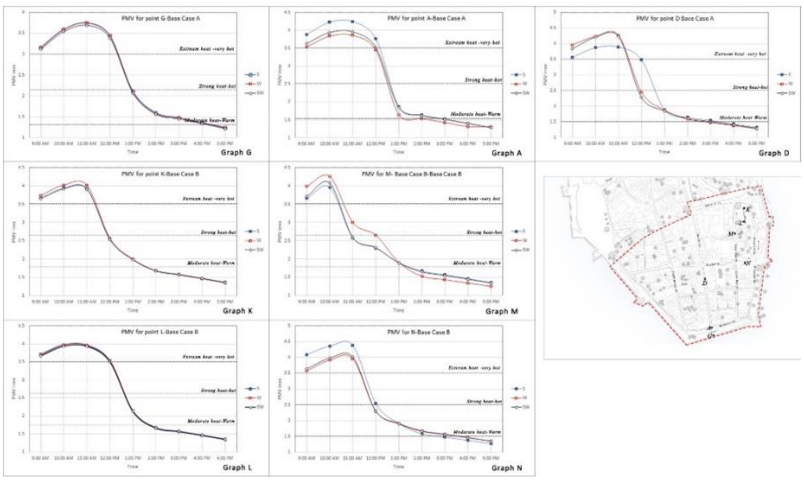


Figure 7: PMV graphs for Site A and Site B

4.3 WIND COMFORT AND WIND VELOCITY

Table 3. Wind Comfort evaluation for Simple Activity Types

Location	Wind cases								
	(S) Wind case			(SW) Wind case			(W) Wind case		
	Sitting (0-2.6 m/s)	Standing (0-3.9m/s)	Walking (0.5.4 m/s)	Sitting (0-2.6 m/s)	Standing (0-3.9m/s)	Walking (0.5.4 m/s)	Sitting (0-2.6 m/s)	Standing (0-3.9m/s)	Walking (0.5.4 m/s)
Rampart St. z=1.5m	✓	✓	✓	X	✓	✓	X	✓	✓
Rampart St. z=1.5m	✓	✓	✓	✓	✓	✓	X	✓	✓
Rampart St. z=1.5m	✓	✓	✓	X	✓	✓	✓	✓	✓
Church St.z=1.5m	X	✓	✓	✓	✓	✓	✓	✓	✓
Church St.z=1.5m	X	✓	✓	✓	✓	✓	✓	✓	✓
Rampart intermediate level z=3.5m	✓	✓	✓	✓	✓	✓	✓	✓	✓
Rampart Top level z=4.5m	X	✓	✓	X	✓	✓	X	✓	✓
Rampart Top level z=4.5m	X	✓	✓	X	✓	✓	X	✓	✓
Rampart Top level z=4.5m	X	✓	✓	X	✓	✓	X	✓	✓
Low court square z=1.5m	X	✓	✓	X	✓	✓	X	✓	✓
Low court square, middle z=1.5m	✓	✓	✓	X	✓	✓	X	✓	✓
Leyn baan St. z=1.5m	X	✓	✓	✓	✓	✓	✓	✓	✓
Pedler st. z=1.5m	✓	✓	✓	X	✓	✓	X	✓	✓
hospital st.intersection z=1.5m	✓	✓	✓	✓	✓	✓	X	✓	✓

Wind comfort for the selected receptor points are evaluated for specified activities in an urban space. Table 4 details out the level of comfort (√- comfortable; X - not comfortable) based on the threshold values defined in literature.

For all wind cases and sites, the wind environment is conducive for ‘Standing’ and ‘Walking’. It is only in the analysis for ‘Sitting’ that a negative impact is seen. At the Rampart level with enhanced wind velocities, the activity of sitting is found to be uncomfortable.

At the Court Square a similar pattern is seen, where, with the enhanced wind velocity, the spaces are deemed to lack wind comfort. The direction of the wind make a slight impact in the spaces around the main public spaces discussed, yet are consistently uncomfortable for sitting in this particular day in June, 2017.

5. Conclusion

The research was designed to evaluate the impact of wind velocity and wind direction on making urban public spaces comfortable. A prominent and successful destination in Sri Lanka’s context - the Galle Fort - a setting that can truly defined as urban was selected. The primary means of mapping the wind impact was in utilisation of a computer simulation software ENVI-met.

Analysis of results were discussed as three interconnected lines of thinking encompassing the relationship between - Urban Fabric Morphology and wind velocity; Thermal Comfort and wind velocity; Wind Comfort and wind velocity.

5.1 FINDINGS AND IMPLICATIONS FOR DESIGN

The findings confirm current knowledge on the impacts of the urban morphology on the wind environment, especially in terms of orientation of streets, open space creation with well-defined physical envelopes and impacts of significant barriers to the wind flow. The North-South, East-West, grid of streets are significant in the Fort in its positive contribution to the wind penetration into the more internal zones of the fabric, thus creating possibilities for open space creation that are still well ventilated.

The impact of a change in canyon geometry is clear in the two prominent areas highlighted in the study - the Court Square and Church Street - where wind paths along the streets in both direction are collected into spaces that have a significant physical envelope, that hinder through flow, yet create enhanced wind velocity within the space. The challenge here is ensure the wind paths continue on, albeit in altered direction such that downwind areas are not deprived of its advantage. Further, the increased velocity in these spaces boarder on discomfort in terms of ‘wind comfort’ for specific tasks such as sitting. Design of the edges of these spaces are crucial in this sense where adequate, and sheltered places for sitting can be created. Elements such as arcades and verandahs, tree places, level changes in the floor plane, vegetation barriers, can be utilised to temper the wind environment. Within space zoning is encouraged, such that a variation created and options given for the varying activities.

The average wind velocity was established as 5.64ms^{-1} for the simulation study based on meteorological data of over twenty years. The upper threshold value for walking is stated as 5.4ms^{-1}, yet the maximum velocities boarder on 3.6 ms^{-1}, thus highlighting the possibility of wind comfort even at higher velocities. This also impacts the thermal comfort, where the spaces evaluated are shown as uncomfortable, although the relationship to higher velocity for higher thermal comfort levels are clear. Thus, other measures such as solar radiation impact reduction within public spaces are essential. The streets are relatively sheltered and in shadow because of the low aspect ratios of the fabric, yet the creation of shade is important in the open areas as well. Overhead planes, tree places, shade structures can be useful to mitigate, while ensuring wind flow.

5.2 LIMITATIONS AND DIRECTIONS FOR FUTURE STUDY

Galle Fort continues to house important public spaces that are extensively used. The study limits its scope to a single day in June, 2018. Thus, an evaluation of the wind environment of the Fort for critical times in a year is deemed essential for policy and design. This will also facilitate the development potentials, and therefore restrictions needed to ensure overall thermal and wind comfort of the environment. The limitations of the software does not account for the nature of the street canyon and open space edges, which can impact the wind velocity. A more detailed study of the areas highlighted in the wind mapping is encouraged.

Morphology changes, albeit in terms of building height, built surface and vegetation - have significant impact in any urban environment. Therefore, urban fabric modification for future development enhancement and overall comfort in the environment is deemed important.

5.3 SUMMARY

The study presents a research flow that encompasses mapping to understand the urban environment, thus identify critical zones in the fabric and ascertain the needs and thus generate possibilities for design intervention for enhancement. This protocol can be easily replicated and built upon to ultimately generate an ‘informed’ decision making process, ensuring the continued and enhanced sustainability of the UNESCO World Heritage Site, Galle Fort, Sri Lanka.

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