Computing the Urban Block

Local Climate Analysis and Design Strategies

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This research develops a method for the analysis, integration and visualisation of climatic parameters in a dense urban block. In order to test this method, a typical urban block in Manila, Philippines, is investigated and results are represented through computational simulation. The translation of latent spatial qualities into visual data with common tools and techniques allows designers to gain an understanding of how to design local microclimates, and inhabitants to gain greater knowledge of the environment. In this regard, this research proposes, contrary to conventional methodologies, the use of analytical tools as the impetus to, rather than the outcome of, architectural design.

Keywords: *Computation, Urban Design, Environmental Analysis, Computational Fluid Dynamics, Simulation*

INTRODUCTION

According to the United Nations, the world's population will hit 9 billion by 2050 (United Nations 2009), with 60 million people per year moving to cities (The World Bank 2013) (Figure 1). This urban migration will put a huge strain on urban infrastructures, stressing transport networks, food production patterns, housing and job availability. Furthermore, the flux in various environmental conditions will create a change in the way urban space is used and perceived. A decrease in air quality or water availability can lead to an increase in ambient air temperature and a lack of physical comfort. The misappropriation of developable land will lead to the dissolution of public social space, leaving behind the inherent cultural qualities of the city. As the world's population moves toward cities, urban density will only increase. In megacities like Dhaka, Manila, and Hong Kong where hyper-density exists, or Karachi, Lagos, and Beijing, where hyper-density is imminent, there must be an understanding of how to approach new urban environments, allowing for both the required density of inhabitants at the scale of the city, but also providing comfortable and productive spaces within the city block. In quickly developing nations such as China, rapid urban development has been highly unsuccessful, leaving entire new cities, designed on a purely formal basis, devoid of inhabitants (Banerji and Jackson 2012). Numerous cities, however, have evolved over a great number of years, dependent on environmental and cultural aspects in which they thrive. By understanding the current and future environmental conditions of these 'Situated Cities' (Weinstock with Gharleghi 2013, p.58), as well as the

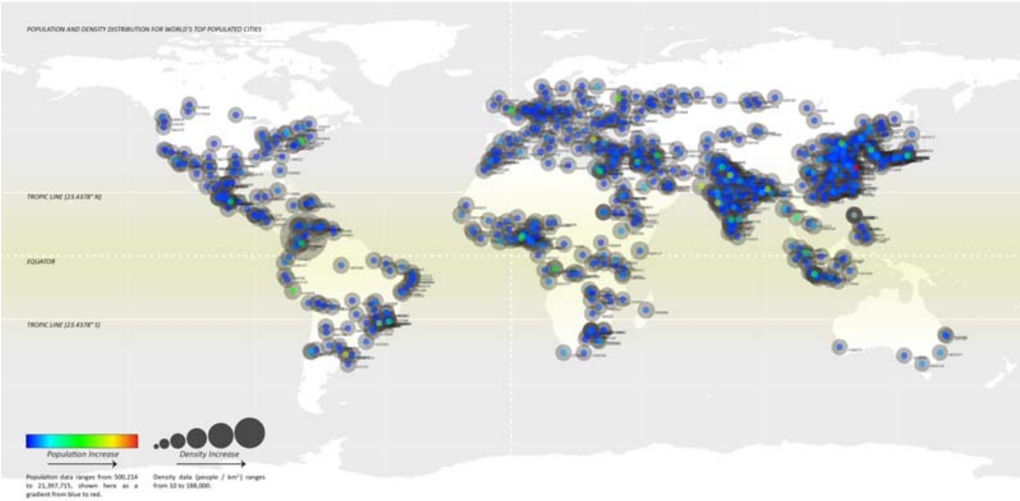


Figure 1
Population and population density of the world's 800 densest cities.

cultural contexts in which they reside, new urban designs can provide a sustainable future for high-density living. Positioning itself within this framework, this research presents a methodology for the analysis and visualisation of the local effects of solar radiation and wind flow on the apparent temperature of an urban block. In order to test the developed methods, the work then describes an investigation on an urban block in one of the densest cities of the world, Manila, on environmental and climatic levels, where the resulting data will serve as a foundation for the visualization of latent behaviour and inherent environmental performance through various digital and physical computational processes. In this respect, the research posited in this paper aims to address innovative modes of digital visualization and representation by moving away from the conventional design-analysis-redesign process towards simultaneous design and analysis methodologies. It is thus argued that understanding the local effects of environmental data on the urban block can lead to the development of more accurate design strategies with regards to the urban and climatic contexts as well as the design of localised architectural moments in urban space.

METHODOLOGY

A prototypical city block is selected and modelled three-dimensionally. The block is then analysed using computational fluid dynamics software to understand its performance in relation to the effects of wind velocity within urban space. Within the construction of a computational fluid dynamics analysis model, a volumetric mesh is generated in order to accurately calculate wind flow, allowing for the observation of its interaction with the buildings at a certain time of year, and its effects on air flow through the urban block. Resulting from this analysis is not only the wind velocity values, but also the point cloud generated from the nodes of the volumetric mesh on which these velocities are plotted. In addition to computational fluid dynamics analysis, solar analysis is used to determine the hourly solar radiation on the building and ground surfaces of the block. Based on the albedo of the building envelopes' materials, a reflected radiation value is determined. Following on from this, the reflected radiation value is combined with wind velocity values mathematically to determine the resulting air temperatures within the urban block due to the investigated environmental factors. The results of this computational process provide an understanding of the differentiated urban space that is characterised by the flow of energy within a city block.

Upon completion of these modelling methods, the data range for a day is simulated visually within a computational environment, allowing the various types of data collected to be organised categorically and compiled into daily representations of urban environmental flows. The simulation gives the user the ability to interact with several types of urban data, aiding in the further understanding of how urban space is generated and differentiated on a local scale (Figure 2).

EXPERIMENT 1: MANILA, PHILIPPINES

As an initial test of the proposed design methodology, a city block in Manila, Philippines was chosen as an initial urban scenario. Manila was selected as an initial test case as it is the densest city in the world. The city of Manila, in 2010, was reported as having a population of roughly 1.6 million people, but a population density of just under 43,000 people per square kilometre (National Statistics Office of the Republic of the Philippines no date). Manila is also located in a tropical savannah climate, experiencing temperatures well over 25 degrees Celcius during the entire year. Since it is located on the tropics, the temperature range is very low. The general wind direction throughout the year, taken from Ecotect data, is distributed between south-east and west, ranging between 3 and 8 metres per second.

In addition to the incredible population density of the city, and the Philippines' tropical climate, Manila is also one of the most environmentally stressed cities in the world, with high levels of air pollution, poor sewage systems, water pollution, misappropriation of land, and heavy motor traffic (United Nations 2014). In the framework of this research, particular attention is given to the air pollution problem. Similarly with most of the developing cities in Asia, air pollution in Manila results mainly from traffic congestion and industrial wastes. The concentration of certain airborne toxic substances emitted by thousands of cars every day contributes to the formation of smog, increasing the risk of respiratory diseases for inhabitants (Wallerstein 1999, p. 689). Additionally, the lack of overall urban planning and development in the recent decades has resulted in a distinctive division in the urban fabric, where vast areas of slums can be seen to be located right next to high-end gated communities. It has been reported that in 2010, an estimated population of 37% Filipinos lived in slums, and the slum population growth rate was 8% annually in Metro Manila, which is the metropolitan district including Manila (Ballesteros 2010, p. 1). Therefore, with the climatic and urban environments presenting huge amount of problems in Manila, the importance of a clear understanding of the spatial relationships to the energy flow of the urban block once again comes into light.

In order to develop a geometrically accurate three-dimensional model, an urban block in Manila, at 14°36'34.84"N and 120°58'30.45"E coordinates was located in Google Earth and imported into Google SketchUp. By evaluating the shadows cast on the imported map against the date of year (27 February 2010), building heights were approximated and modelled three-dimensionally. With the use of computational fluid dynamics (CFD) analysis in CFX for ANSYS, the wind velocity in the block is simulated. The computational mesh density generated in CFX can be controlled in order to both increase the accuracy of the simulation, but also the definition of the point cloud that is then used for further analysis. This point cloud and its corresponding velocity values are imported into Grasshopper, Rhino's parametric modelling tool, and visualised three dimensionally on the block morphology. With this data in the modelling environment, a series of urban physics calculations are made in order to accurately describe the effects of temperature and human comfort within the urban block condition. Firstly, Ladybug, an environmental analysis tool in Grasshopper, is used to generate tem-

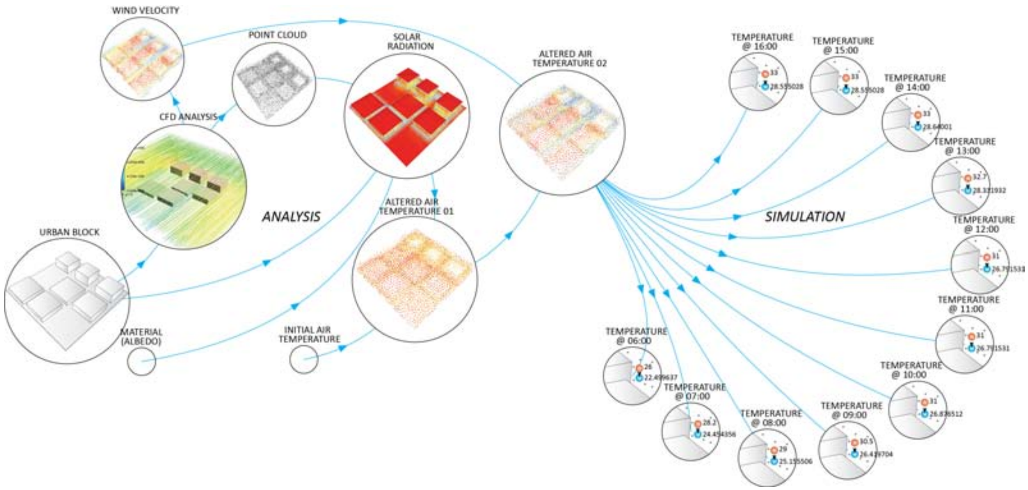


Figure 2
Design Methodology. Wind velocity data taken is analysed using fluid dynamics analysis and combined with solar radiation data, along with global temperature and humidity values in order to calculate the ambient air temperature for each point on a point cloud within an urban block. This data, collected hourly, is then simulated computationally as a visualisation tool.

perature, humidity and energy data for the specific site. Reflected solar radiation is calculated by defining the albedo of the vernacular building material. These radiation values, initial temperature values, the wind velocity values found in the computational fluid dynamics analysis, and general relative humidity values are then linked using Steadman's Apparent Temperature equation (Australian Government Bureau of Meteorology no date; originally attributed to Steadman 1994). This mathematical model thus generates the data for understanding the environmental effects and spatial consequences of urban block morphologies. During the second phase of the research, the results of the environmental calculations, extracted hourly throughout the summer solstice, are transferred as three-dimensional data into the open source environment Processing (Figure 3). As an object-oriented programming environment (OOP), Processing allows for the delineation of each set of environmental data as a class; each class can then interact according to specific rules in order to produce emergent data patterns on a global level. With the incorporation of physics libraries in Processing, this imported environmental data become input parameters for a series of simulations which seamlessly link the distinct instances into a specified period of time, exploring the effects of variations in wind velocities, ambient temperatures, and apparent temperatures. By merging separate sets of data which has been created for each hour throughout the day, it is possible to explore how energy flow is differentiated for a certain period of time on a local scale (Figure 4). It is believed that this tool can be very advantageous for the designer, as it can help in the understanding of what types of architectural interventions can be necessary in improving the environmental quality of urban space.

RESULTS

The experiment provided results, on average, of a three to four degree decrease in apparent temperature across the points in the point cloud due to wind flow, combined with local solar radiation values and global temperature and humidity data, modelled mathematically within an accessible three-dimensional modelling environment. . The potential to combine solar and wind flow data at a resolution useful for architects and designers is significant, while the largely successful results from the first test prove an intelligent and logical methodology. The initial experiment on the Manila block shows the pos-

Figure 3
Wind velocity taken from computational fluid dynamics analysis is imported in the Processing environment for the simulation and representation of microclimatic data on an urban block in Manila, Philippines.

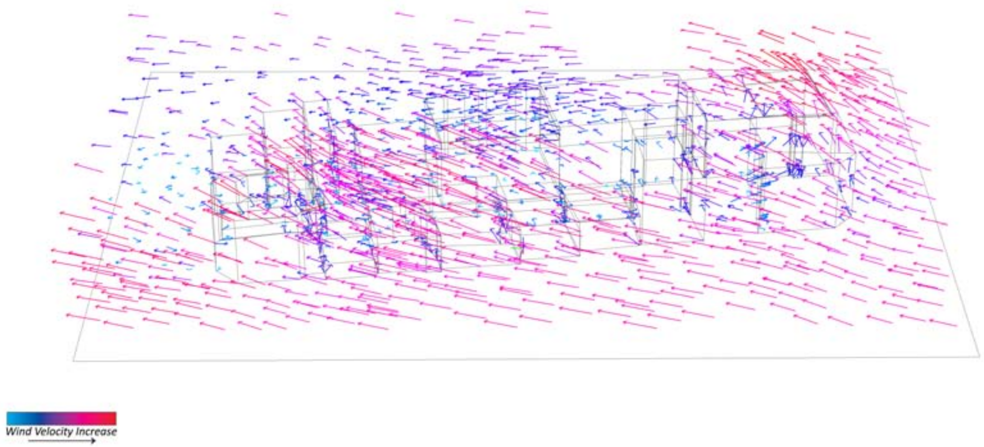
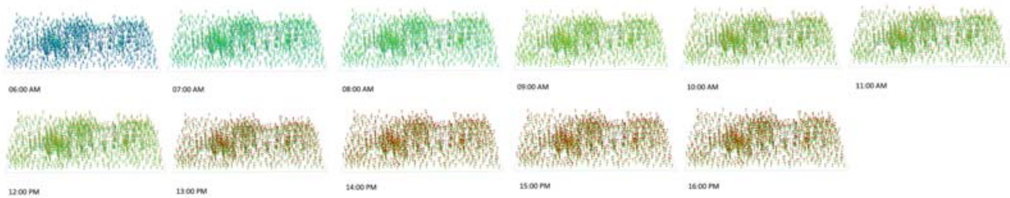


Figure 4
The change in temperature is mapped on the Manila block, providing a clear representation of the change in apparent temperature due to solar radiation and wind flow.



sibility for Grasshopper, a tool used by a wide audience, to compile climatic data within one model and one environment. Grasshopper allows for the visualization of this data at one specific time, or as an average over a set time period. While this may be useful in a large number of scenarios, the visualization of change throughout this time period would give a better understanding of climatic conditions and the performance of urban space. Thus, the implementation of Processing in creating a simulation, which covers a time span and enables the user to interact with data visualization, becomes incredibly important within the scope of this experiment. Even though the inclusion of high-end engineering and analysis software is becoming more widespread, the understanding of these results has not necessarily become straightforward. In this regard, the visualization of the spatial effects of climatic conditions in Processing becomes a valuable tool for design (Figure 5).

DISCUSSION

The results from Experiment 1 provide some excellent opportunities for further exploration, along with a series of questions and problems that require resolution. While the integrated method provides useful results, a series of modelling issues must first be resolved. With regard to mathematical modelling, there are two environmental calculations that need development. Solar analysis through the Ladybug plug-in provides accurate data for sun path analysis

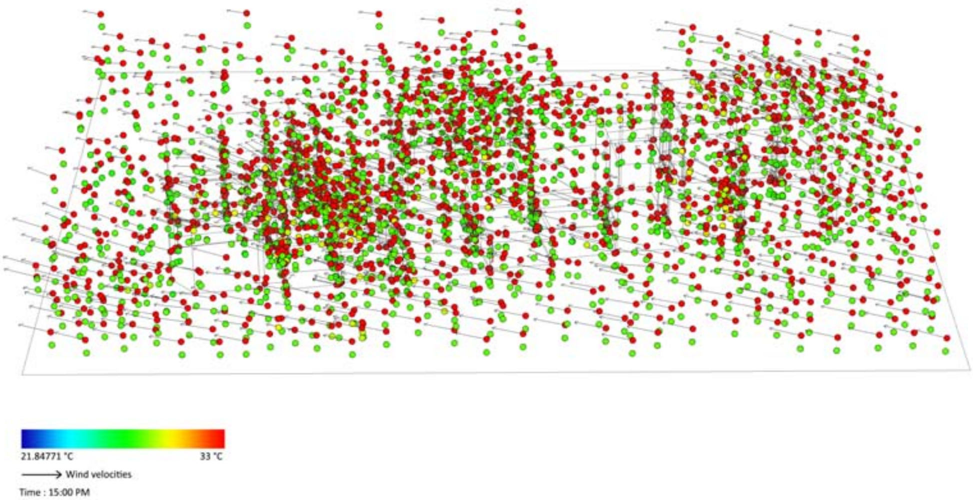


Figure 5
Visualising climatic data verifies the change in apparent temperature over time, but also describes how the differentiated change in temperature creates varied microclimatic effects.

and subsequent solar radiation on the building surfaces in the three-dimensional model. The reflected solar radiation is approximated with an albedo factor, and applied on the surrounding points within the point cloud, giving a baseline understanding of the behaviour of reflected energy on surrounding air temperature, at a resolution useful to designers. However, the change in air temperature is currently calculated using the AT formula previously described on each point within the generated point cloud. While this may provide an understanding of localised effects, the precision of the location affected can be improved by refining the point cloud on which calculations are based. This would increase the precision in the correlation between the point of calculation on the building surface and its coupled point of reflected radiation, and thus apparent temperature. Additionally, Steadman's Apparent Temperature formula supposes that wind speeds are calculated at 10 meters above ground; since this research aims to achieve an understanding of local climatic differentiation, this seems to be an incorrect calculation. Further investigation is necessary in order to refine this mathematical relationship.

While digital simulation in Processing has helped in the representation of local effects throughout a given period of time, it has also uncovered an issue in visualising hourly and daily data within a single model. In order to visually understand the relationship between initial and apparent temperatures throughout a daily cycle, the global temperature range (that is, the lowest and highest values of the combined initial and apparent temperature values) has been used, and nodes assigned a colour gradient with reference to this data. However, as the global temperature range is larger, the difference in colours is much greater than it would be if colours were mapped within a local hourly range. Although this creates a difficulty in representation, it is preferred to maintain the global range and ensure accurate comparison while developing ways to improve the data's legibility.

Along with refining the methods and techniques as indicated within this discussion, future research hypothesises that taking this computational method to the physical environment will aid in the understanding of the effects of environmental data on the selected urban block. For this purpose, a scaled phys-

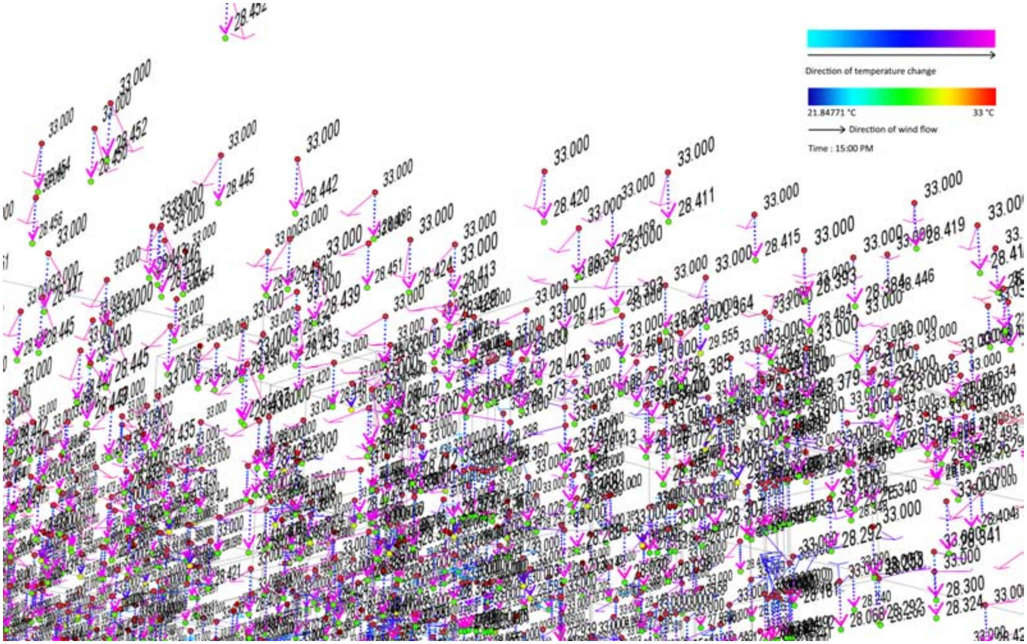


Figure 6
Computational simulation in Processing allows for the visualisation of numerous data within one variable model.

ical model of the urban block will be fabricated and overlaid with an interactive arrangement which will carry out the spatialisation of various types of environmental data, including wind flow, actual temperature, and perceived temperatures. This task will be realised through the physical computation environment Arduino, which will be in continuous communication with the simulation generated in Processing. As such, it will be possible to physically manifest environmental data and its alteration over time in three-dimensional space by using various media, including LED's, movable pins, and projection-mapping, simultaneously disseminating the correlations between separate data sets.

A further observation of this experiment, while not specific to the architectural scope of this research, is with regard to the employed computational environment. Modern computing processing capacity has rendered it possible to use advanced modelling and complex simulation tools on a personal laptop. The fact that various 3D-modelling, analysis, and simulation tools involving complex physics calculations can be operated on a laptop presents itself as a major advantage for the research, as it creates an effective digital workflow between separate platforms. Furthermore, the ease of using various complex modelling and simulation tools on a laptop also enhances the interdisciplinary nature of design which has been improving in the recent decades, making it possible for a smooth communication between different professions involved in design. In effect, this development acts as a constituent in one of the major goals of this research, which is to create innovation in digital visualization and representation tools by simultaneously integrating design and analysis techniques.

CONCLUSION

The integration of different types of environmental data inside one tool makes it easier for the designer to understand the correlations between these various data types (Figure 6). The methodology developed in this research is expected to be implemented as a critical part of conceptual design process. In effect, this tool can become an aid in bridging the gap between conceptual design and environmental analysis, in return helping the designer to make informed decisions about potential urban interventions on a selected site rather than conforming to intuitive choices.

The translation of latent spatial qualities into visualised data uncovers significant potential in the understanding of the performance of the urban block, incorporating existing density distributions with effective climatic and productive spatial models. Through the employment of feedback from the initial computational model and physical prototype, urban analysis can be implemented as a methodology to anticipate future scenarios for design possibilities. In this respect, the current research methodology applied in a specific urban block in Manila will be advanced in order to investigate a series of additional urban blocks in the world's most populous cities.

Furthermore, it is argued that the research has two major future potentials, which are related to the architect and the inhabitant respectively. From the architect's point of view, the research outcome can serve as a design tool allowing the architect to predict the impact of future design proposals in the urban context. From the inhabitant's point of view, the outcome serves as a visualization and representation tool which enables the user to interact with environmental data and fully understand its implications on the urban scale. As such, "Computing the Urban Block" proposes, contrary to conventional methodologies, the use of analytical tools as the impetus to, rather than the outcome of, architectural design by enhancing their potential as a digital design and representation tool.

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