Investigating the Potential of Utilising Simulation Studies to Identify UHI Mitigatory Strategies in Proposed Cities

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Abstract*: Rapid development of urban areas catalyzed the movement of people from rural areas to urban areas. This led for the demand of more dwelling places. Urbanization and industrialization cause for the replacement of permeable land cover into impermeable materials. More solar radiation has been absorbed by impermeable materials as it has thermal bulk properties and cause for the increase of urban temperature. Change of urban microclimate caused the phenomenon identified as urban heat island effect which is identified from the temperature difference between urban and rural area. In Sri Lanka few researches have conducted on UHI effect for developed and existing cities. Identifying potential UHI mitigatory steps is vital when designing urbanities. Therefore, analyzing UHI effect and possible mitigatory strategies for proposed cities through simulation studies are highly beneficial in developing sustainable cities. The research focused on investigating the potential of utilizing simulation studies to identify UHI mitigatory steps for proposed cities in local context. Rhino 3D simulation software was utilized for the study. The paper presents the results of initial studies conducted. Research methods and workflow developed through the study can be utilized to evaluate the UHI effect, mean radiant temperature (MRT) and universal thermal climate index (UTCI) to identify the outdoor thermal comfort. This software and methodology can be used for future developments to identify the UHI effect as a result of the completion of project and mitigation methods that can be used to negate the UHI effect and enhance the human comfort.*

Keywords: *Urban Heat Island effect, Outdoor thermal Comfort, Rhino 3D*

1. Introduction

With the rapid urbanization trends and industrialization, people started to move from rural areas to urban areas. This caused for an increase of the urban population and demand for more dwelling spaces. Growing cities had to developed either vertically or horizontally. That will cause for warmer climatic condition by blocking urban ventilation and absorbing solar radiation by their impervious materials (Mirzaei, 2015). According to United Nations report, 68% of world population is predicted to be increased by 2050 in urban areas. Specifically in Asia and Africa this increase might be close to 90%. Increase of urban population demand for more dwelling places by adding negative impacts such as urban sprawl, high carbon foot print and urbanization (Vuckovic et al., 2019). Demand for dwelling places and unplanned developments replaced the green cover and pervious surfaces by impervious surfaces such as bricks, concrete, tiles, bitumen, asphalt, etc. of buildings, roads and parking lots. Compared to the ambient rural areas, these materials have a significant thermal bulk properties and surface radiative properties. Therefore, natural environment and ecosystem is negatively affected by urbanization and industrialization (Cinar, 2015; Ranagalage et al., 2017;Aflaki et al., 2017). Different human activities and anthropogenic emissions effect to the atmospheric composition and high air temperature. All these activities affect to the urban microclimate. Changed microclimate of atmosphere cause the phenomenon identified as urban heat island effect. This phenomenon can be identified from high air temperature in urban areas compared to suburban areas. (Anniballe et al., 2014; AboElata, 2017; Qaid et al., 2016; Aleksandrowicz et al., 2017). The maximum temperature difference between rural and urban areas can be high as 5 ^{0}C - 15 ^{0}C (Wanphen and Nagano, 2009)

A. Research on uhi effect in global context

Numerous studies on UHI have been conducted in international context. Studies have focused on the effect of surface reflectance on UHI in many researches. A study reveals that the roofing system is the main envelop element which is capable to increase temperature more than 30^0 C, than ambient temperature (Doulos et al., 2004). As mentioned by Levinson et al., (2005) initial reflectance of 0.04 of a built up roof is increased to 0.8 after coating with a smooth, black asphalt layer. Reflectance of a single ply membrane can be changed to 0.2 from 0.04 by applying a gray coating whereas with white coating it is changed to 0.8. Initial reflectance of 0.1-0.2 of bitumen with mineral surfaces can be modified by coating white to the top, which changes the value of reflectance to 0.65-0.7. Oleson et al., (2010) have observed white roofs have a substantial effect on urban temperature. These applications decrease the maximum temperature by 0.6K, minimum temperature by 0.3K and annual heat island by 33%. A research done by Bozonnet et al., (2011) have mentioned cool roofs can reduce the surface temperature by 10^0 C. According to Pisello et al., (2015) indoor operative temperature decrease up to 2.6^0 C and temperature of the external roof surface could be decrease up to 19.8^0 C by applying only cool roof membrane. Overall temperature will be reduced by 3.1^0 C with combination of two cool solutions.

B. UHI effect in local context in existing cities

Several researches have been conducted on climate changes and UHI effect in existing cities in local context Maheng et al., (2019) have conducted a research to identify the effect of urban greenery for urban heat island effect in Colombo city by a simulation method. it has been observed that average temperature in Colombo can be decrease by 0.1^0 C by increasing greenery up to 30%. Perera,(2014) has observed the effect of materials which used in street canyon to the urban heat island effect in Colombo. According to the results, highest UHI intensity has been recorded by aluminium cladding in commercial area as 2.87^{0}C whereas aluminium cladding in sea front zone had the lowest UHI intensity of 1.87^{0}C.

Emmanuel et al., (2007) have stated that the increasing heigh to width ratio cause decrease in the air temperature within the canyon. However, as a negative impact could affect the wind flow through the street canyon as well. Further, it is identified that physiologically equivalent temperature will be decrease about 10^{0}C by increase H/W ratio from about 1 to 3. Herath et al., (2018) have conducted research on implication on urban green infrastructure to enhance microclimate in tropical urban context. It has concluded that applying trees in curbsides, 100% green roofing, 50% green roofing, 50% green wall and combination of trees in curbsides+ 50% green roofs+ 50% green walls can reduce the temperature by 1.87 °C, 1.76 °C, 1.79 °C, 1.86 °C and 1.90 °C respectively. Accordingly, this suggests that the surface fraction has a contribution for changes in urban heat island effect.

C. Need of identifying the UHI mitigatory steps in proposed cities

Urban planners and researchers have identified the egregiousness of this phenomenon and have initiated research on

UHI effect of future developments and urban changes. According to (Amorim et al., 2020), future developments in urban areas cause to increase the air temperature due to the change of land cover by buildings and impervious materials. Rathnayake et al., (2020) highlight that future trends of anthropogenic heat need to be studied before implementing future developments as it has a crucial impact on UHI. Previous scholars mostly focused on UHI effect, parameters and mitigation methods for historical and developed existing cities. Internationally reseach has been conducted for developing and proposed cities as well for existing and historical cities to identify the microclimatic changes with new developments and their negative impacts such as UHI effect. In local context there is a research gap in simulation studies for developing and proposed cities to identify future microclimatic changes.

D. Research studies on UHI effect in future cities

Yi and Peng, (2014) have researched on effect of microclimate change to indoor and outdoor comfortability in 2012 and 2050. Future predictions have been conducted through computational modelling. Interaction of outdoor microclimate with indoor thermal performance of a building has been identified through series of numerical simulations and prognostic visualization. According to results, outdoor microclimate was predicted to be increased by 1.7^0 C from 2012 and indoor thermal condition by 1.8^0 C. After applying passive cooling methods indoor thermal conditions were predicted to be decreased about 1.2^0 C and 1.4^0 C in 2012 and 2050 respectively. The research done by Amorim et al., (2020) evaluated the consequence of land use changes on summer temperature. Land use changes in 2030 and 2050 were simulated by computational modeling. Results depicts that the land cover changed by buildings and impervious surfaces cause to increase the air temperature by 0.29 °C and 0.46 °C in 2030 and 2050 respectively in Stockholm. Further, it is mentioned these data are supportive for urban planners to deal with urban adaptation to climate and good exchange of fresh air will help for drastic change in air temperature.

Fahmy et al., (2020) have discussed present and future microclimate change effectiveness to indoor comfortability with new suburban residential developments. Envi-met and design builder simulation methods were used to predict the microclimate change with and without of urban canopy green from present to end of 2080. Results signified that, applying materials such as green roof and green facades for construction of building envelope and design surrounding with greenery help to improve outdoor microclimate and energy consumption while maintaining indoor thermal comfortability. Naboni et al., (2019) have conducted a study on digital workflow to quantify regenerative in urban areas in the context of climate change. The research focus on climatic change in future with new developments. Digital workflow has been developed through rhino 3d software and grasshopper. Biophilia, outdoor human thermal comfort, energy use and production and daylight performance are the key factors considered based on data exchange and synergies across the different tools.

E. Experimenting simulation to identify UHI mitigatory steps in future cities in local context

The research was initiated to identify the potential of using simulation studies to identify the potential UHI effects in future cities of local context and to find mitigatory solutions. This research will focus on the methods and software that can be used to identify the effect of UHI and climatic changes as a result of future developments. Methodology of this research can be used for future studies to do quality and effective developments. In Sri Lanka, proposed Port city development is the largest city development which is proposed as an extension of the central business district Colombo (CBD). As the port city is in the developing stage, still there is an opportunity to simulate the microclimatic change that could take place after the completion of the project and take relevant decisions and methods to mitigate the negative impact. Therefore, Colombo Port City was selected as the case study to continue a pilot study. The paper presents the findings of the pilot study conducted to establish a simulation work flow to identify the UHI effect for a proposed city in local context.

F. Simulation software applications

Numerical modeling methods are used in order to analyze UHI effect. There are several different softwares available to carry out the modelling. Some software solutions have merged different models to get a better performance while others use the traditional computational simulation methods. Softwares vary with its capability of detailed building performances, time taken for simulation and analysis methods. Envi met, ADMS temperature and humidity model, RayMan, CitySim Pro, Ladybug Tools and Autodesk CFD, Ecotec, CEA (City energy analysis), Urban Modelling Interface (UMI) are some of urban building energy modeling softwares which are used to calculate UHI effect (Ferrando and Causone, n.d.) ("Towards urban building energy modeling: a comparison of available tools," n.d.).

CitySim numerical modeling software aids in quantifying the energy demand at the outdoor radiative environment and in urban scale ("CitySim Software," n.d.). City energy analysis (CEA) software is developed to assess energy system rationalization and urban energy use. CEA can be used to assess diverse urban scenarios based on, carbon emissions, energy and financial criteria. Urban Modelling Interface (UMI) is a Rhino based interface. It calculates embodied energy, daylighting, operational energy use and walkability at the urban scale. ADMS-TH is an integral operational model. It facilitates to analyse the relative humidity within urban areas and air temperature change caused by land use change. Rhino 3D and ladybug tools are used to sky view analysis, solar radiation studies, outdoor thermal comfort analysis, urban heat island analysis and more ("Referring to Rhino/Grasshopper in scientific papers - Research Projects - McNeel Forum," n.d.). Envi-met is one of the widely used microclimatic simulation tool. Comparing with all numerical simulation tools, ladybug is linked with lot of supportive software and explored its output in a wide range. Therefore, considering the quality and accuracy of outputs and other offered benefits, ladybug numerical simulation tool in grasshopper has selected for this research ("Ladybug Tools | Dragonfly," n.d.). Rhinoceros 3D is a computer aided design application software. This used as the interface to develop the geometry of domain for the energy simulation. Ladybug tools are the numerical simulation tools which used for this research ("Ladybug+Honeybee for Grasshopper, Baker Lighting Lab," n.d.). These tools work in grasshopper interface which act as the main inter connector of the conceptual 3D model and simulation tools. Ladybug tools are mainly divided as ladybug, dragonfly, butterfly and honeybee. These individual tools collectively collaborate for the overall simulation. Only ladybug, dragonfly and honeybee tools have used for the simulation of this research.

Ladybug tool is allowed to import and analyze weather data in grasshopper. It helps to develop the urban and rural weather data as well as historical and future weather data for simulations. Ladybug is the tool which used to visualize the data of every simulation tool. There are different types of graphs available as per the requirement. These graphs are allowed to more detailed for better understanding.

H. Dragonfly tool is used to develop the city characteristics more accurately. It models large scale climatic phenomena such as climate change, urban heat island and local climate factors such as topography. Urban weather generator tool is a component of Dragonfly. It morphed the rural weather data to generate new urban weather file in "epw" format. It is the main component which need to identify the UHI effect. Honeybee tool used to create honeybee zones in 3D model for energy simulation. It connects validated introduced as separate layers in Rhinoceros interface. This model is linked with ladybug tools for the simulations through the grasshopper interface. Grasshopper is a visual programming language that is a plug-in of Rhino 3D for more complex simulations in energy modeling. More specifically researches about climatic changes and UHI effect used Lady bug tool set for energy modeling. Each component has specific energy simulation. Final simulation is done by connecting this toolchain by assembling

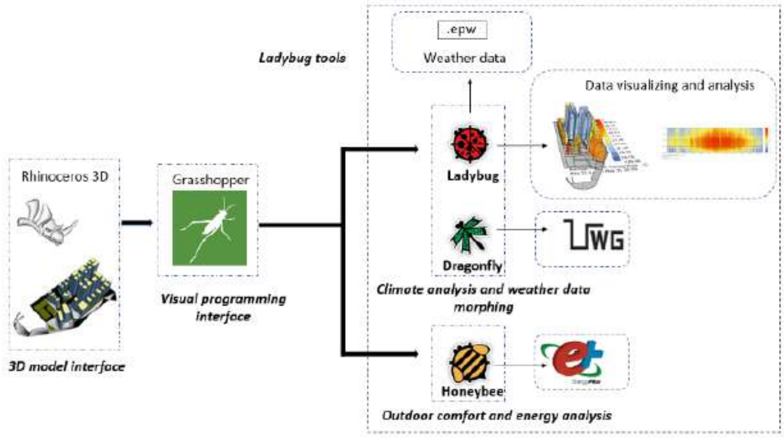

Figure 1 -Interconnection between Rhinoceros 3D, Grasshopper and Ladybug tools

simulation engines to grasshopper such as Radiance, EnergyPlus/OpenStudio for building energy and comfort, daylighting and lighting simulation. Workflow simulate the mean radiant temperature (MRT) and Universal thermal climate index (UTCI) to measure the outdoor thermal comfort perceived by pedestrian.

This 3D modeling tool become one of the standard tools for designers and architects. Model can be developed in the Rhinoceros interface or can be imported from SketchUp or Revit softwares. Grasshopper is the interface of ladybug tools and other energy plus simulation tools. Case study domain can be developed in the Rhinoceros 3D interface. Auto cad drawing should be imported to Rhinoceros 3D to develop the building blocks according to the rules and regulations of the selected domain. Buildings and land use properties such as roads and pavements separate script. Building energy simulation is done by energy plus, RADIANCE, Daysim and openStudio engines. It is included in honeybee component. Outdoor microclimate conditions were presented as MRT and UTCI values which represent the outdoor thermal comfort. Results visualizing is done with the help of ladybug plug-in. As the overall simulation is a combination of individual tool chain, different scripts and workflows has to be developed. Case studies will be conducted in with several phases. For each phase separate script has to be developed.

2. Methodology

As the research is done based on a predictable and imagine situation, conducting a pilot study is needed to identify the application requirements and possible errors. Therefore, a pilot study was done for a small-scale building context to be familiar with the new software and to confirm that all workflows are feasible to be implemented. After finalizing the workflow of each simulation phase, surface urban heat, canopy layer UHI and boundary layer UHI has been calculated. Getting familiarized with this software solution took a steep learning curve as the pilot study had to do be done with lot of experiments to develop the correct

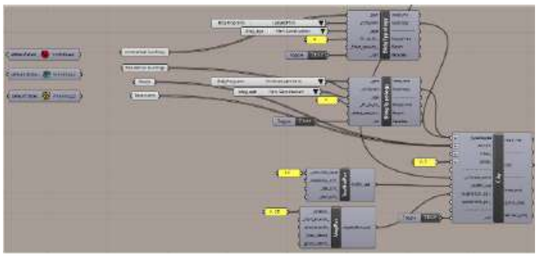

Figure 2 - Urban heat island simulation workflow

workflow. A considerable time was taken to study the software and identify all the simulation errors and create the correct workflow for each calculation. An area of the Port city Colombo was selected as the case study as it is the largest proposed city in Sri Lanka. By running each workflow for each scenario in the pilot study, temperature differences and effectiveness of material and greenery on surface UHI, boundary layer UHI and canopy layer UHI effect was identified.

A. Urban heat island simulation workflow

This script was developed to simulate the UHI effect of port city after the completion of project. Ladybug plug-in and dragonfly plug-in was utilized for the simulation. Output is taken as temperature differences and the results highlighted that there is a UHI effect in Port City.

B. Modeling the selected domain characteristics

Dragonfly city component is the feature that is used to develop the urban context. It is linked with several parameters which needed to model the actual context of the urban area. According to the UHI definition, it is a temperature difference between urban and suburban areas. Weather data of the urban area is morphed with reference to the rural weather. Building volumes are selected as Breps in grasshopper. Each building volume is moderated with its typology. Building typology component can group the buildings in the context according to building program, age, floor heights, fraction canyon. Each building typology is connected to the Dragonfly city component. Roads and pavement list of Breps, tree fraction, grass fraction, climate zone, traffic parameters, vegetation parameters and pavement parameters are the inputs which were needed to develop the urban city context. These inputs can be separately more detailed by using its components. Building typology factors and greenery has input according to the regulations of port city. Weather data was taken from EPW weather file and was developed according to the weather conditions of port city. Output of dragonfly

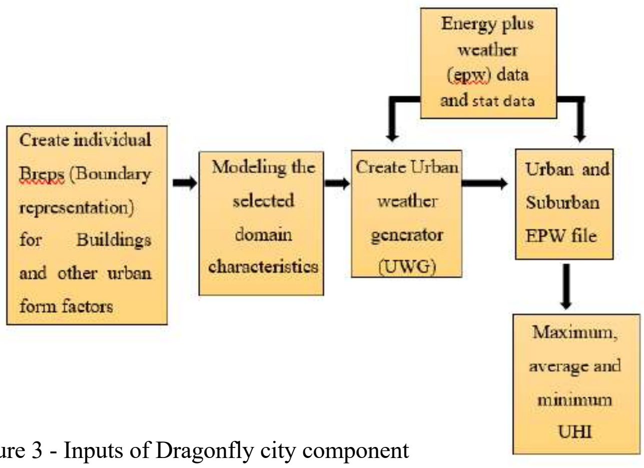

Figure 3 - Inputs of Dragonfly city component

city componentlinked to the urban weather generator model to simulate the UHI effect.

C. Create urban weather generator model

Palme et al., (2019) has developed Urban weather generator model by coupling an atmospheric model with a Building Energy Model (BEM). Urban microclimate is account by urban weather generator dragonfly plugin. UWG change the microclimate in urban canyon compared to the conditions of

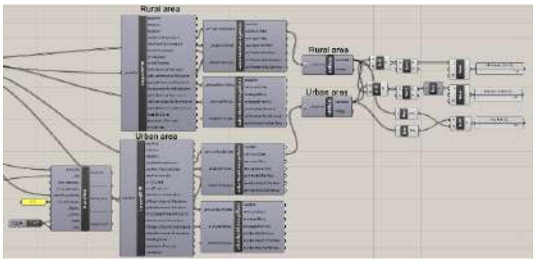

Figure 4 - Urban weather generator (UWG) model

weather stations in outside of the city. Future weather file generates by synthetic weather generator by processing UWG. UWG model urban heat island and calculate hourly values of urban air temperature and humidity. As the UHI definition, it is the temperature difference between urban and rural area. Therefore, temperature difference is calculated from the values of energy plus weather data of urban and rural area. By input all the geometric data, UWG run to simulate UHI value and simple custom Grasshopper code filters give average, minimum and maximum UHI values.

D. Result visualization

Ladybug plugin work as a data visualizing tool. Dry bulb temperature of rural and urban, outdoor thermal comfortability, and other relevant data can be presented as graphs which is easy to compare the differences to get a better understanding. Average data can be presented as hourly, daily and monthly in graphs. Building surface variations can be displayed by changing the colors in the model.

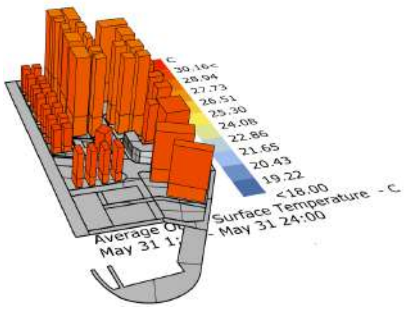

Figure 5 – Results visualization

E. Material and greenery variation workflow

Honeybee (HB) is the grasshopper plug-in which used to change surface materials and greenery in buildings. Honeybee create HB Zones in building context. Then it is divided into individual surface as roof, walls and floors. Materials can be easily applied to each surface.

HB provides opportunity to apply different materials in different surfaces in the same building when individual surface are select by sliders. Figure 6 shows the set of surfaces selected to import surface materials for this research. Likewise for other materials applications, relevant building surface should be selected.

In honeybee, some materials are available in HB Library. And also, materials can be created according to the requirement. Actual property values need to be added when developing the materials. Individual surface material and ratio can be changed in this plug-in. Material creation has another set out workflow. Individually created materials has to be added to HB library before using.

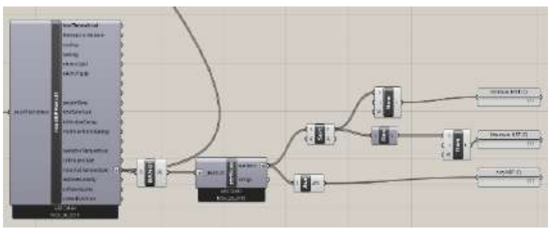

Figure 6 - Surface selection from HB zone workflow

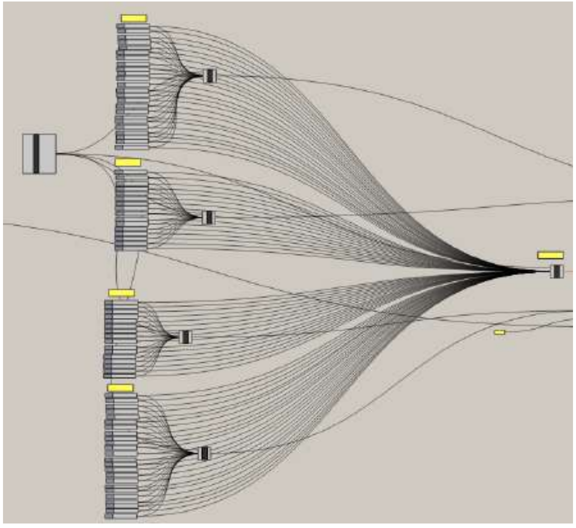

Figure 7 - Universal thermal climate index simulation workflow

F. Outdoor microclimate analysis workflow

Outdoor thermal comfort is simulated by another component of Honeybee plug-in. Mean radiant temperature (MRT) and universal thermal climate index (UTCI) are the metrics used to define the outdoor thermal comfort. View factor of every surface is calculated by the indoor view factor component. It gives the view factor info

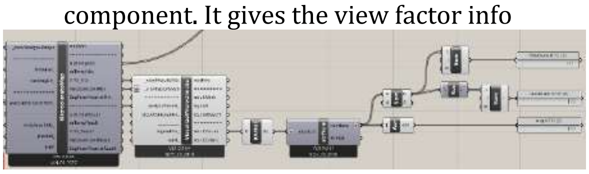

Figure 8 -Mean Radiant Temperature analysis workflow

which needed to simulate the outdoor comfort recipe component. View factor mesh and outdoor surface temperature are the other two inputs which needed for outdoor comfort recipe component. Finally, microclimate map defined universal thermal climate index. “Read EP result” component gives MRT values for simulate outdoor thermal comfort of pedestrians.

3. Discussion

The research is conducted on a proposed city. Therefore, only the zoning and rules and regulations has been completed up to now. The constructions are in the infrastructure stage at the moment of this research done. Therefore, building designs are not finalized. As the Port city authority is restricted giving data even for an academic purpose due to high security and commercial reasons, data has been collected to an extent. Because of that, by using zoning map and rules and regulations, 3D model has to be developed in to its maximum capacity with the help of Rhino 3D for the pilot study. As the simulations of this study based on the software, it should be more accurate and suitable. But there can be limitations in performance in student versions. Finally, the workflow and the scripts which were developed in this research can be used for proposed and future developments in the local context. And also, the results can develop more detailly by modifying the scripts. This method can be used mitigate the climate changes and UHI effect which will be emerged due to the future developments and proposed cities. According to above process, the method which can be used and the effect after the completions of the projects can be identified. Therefore, using this method is an important factor to protect the atmosphere and enhance the human comfort in future.

4. Conclusion

Urban heat island effect and climatic changes in urban context is a suffering problem in present. Therefore, researches have done several studies to mitigate the current situation and enhance the human comfort. In local context, researches have done only for existing cities. In other countries, they have conducted several researches regarding proposed cities. Due to the rapid developments in urban context, climatic conditions can be worst in future. Therefore, there is a need of doing a study about the effect of climatic condition and UHI effect before implementing a project in local context. This research was done regarding the software and the methods that can be used for those studies. Rhino and grasshopper has been identified as the most suitable software and the methodology is developed to the mitigate the UHI effect in this research. This research will help in advance to protect the atmosphere and mitigate the UHI effect from future developments and proposed cities by identifying the most suitable materials and mitigation methods.

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