A new workflow of urban scale 3D modelling and simulations to test the implications of the latest area-based FAR regulations on microclimate in the megacity Dhaka

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Abstract

The latest DAP (Detailed Area Plan 2022-35) for Dhaka has proposed an area-based FAR (Floor Area Ratios) decided on the basis of existing population density, road properties, civic amenities, and other physical characteristics of an area. Although the new building regulations attempt to control the building density, its impact on the city's microclimate remains unclear. In this study we attempt to examine the impact of the above FAR regulations on the immediate microclimate compared to the existing building situation with the use of 3D modelling and microclimate simulations. It introduces a novel workflow to automatically extract, collect, and pre-process the building information (building height, types) from GIS data to generate 3D models for urban blocks for the existing conditions. The 3D model is implemented using Python programming and scripting language in a web-based interactive computing system (Jupytar Notebook) in a Rhyno-Grasshopper platform. Existing urban blocks are further developed/ altered to apply the new area-based FAR regulations to generate the future scenarios. Next, LadyBug tools (Urban Weather Generator in Dragonfly) are used to generate urban microclimate conditions for both existing and future scenarios which will show the implications of the area-based FAR regulations on microclimate in the megacity Dhaka. Five scenarios with distinctive urban morphology patterns are selected for the purpose of comparison. The findings of the study will help the policymakers and urban planners in Dhaka to understand the impact of the new building regulations and take necessary steps to rectify the policies before they take effect. Besides, the novel methodology developed through this study can be applied in other cities to test the impacts of future morphological patterns in terms of microclimate and building density.

Highlights

- Automated Urban 3d Modelling
- Simulation
- Building Code

Introduction

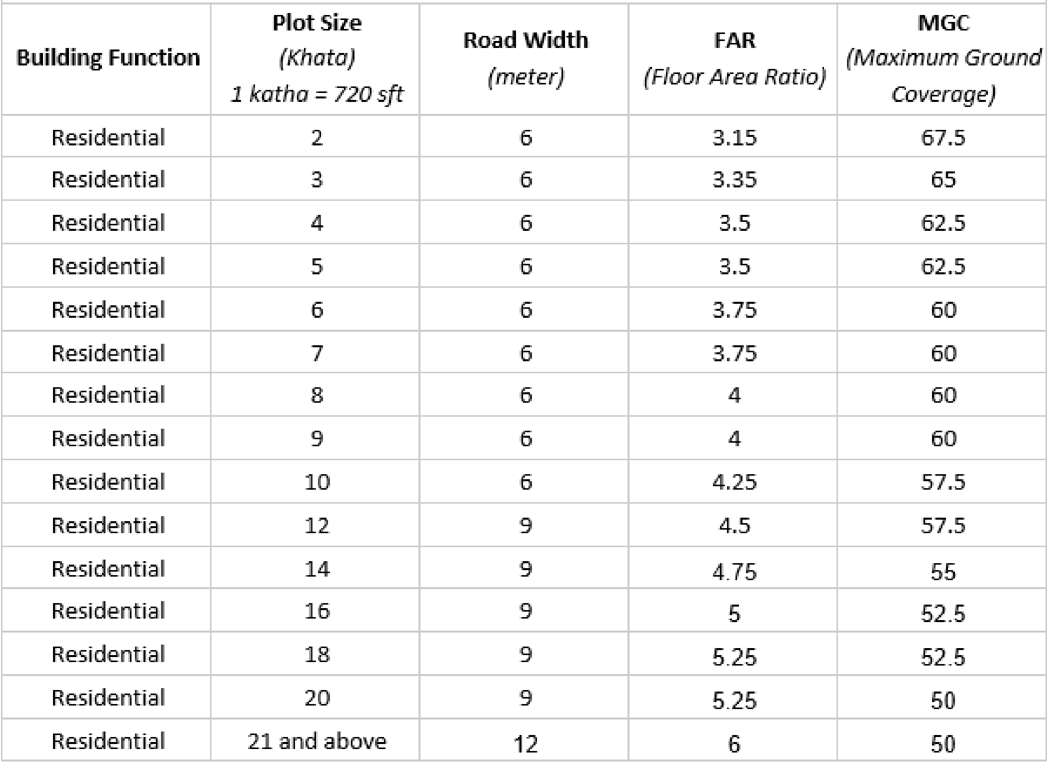
With almost 87% illegal and unauthorised buildings and constructions, the microclimate in the megacity of Dhaka is rapidly deteriorating. It has been ranked as the most polluted city in the world. Although the air quality is not a direct effect of the building morphology, the built form plays a significant role by trapping the pollution, which is further exacerbated by the urban heat island effects. In response to the challenges, the government of Bangladesh has introduced several building rules to regulate the construction of buildings in the country, including Building construction rules 1996, 2008, and 2022.

In 1996, the government of Bangladesh introduced the Rajuk Rules to regulate the construction of buildings in the country. The rule allowed a maximum height of 6 stories for all buildings, regardless of the plot sizes. The only consideration was the setback, which was determined based on the road width. As a result, many buildings were constructed with little open space, resulting in a lack of ventilation and light.

In 2008, the government introduced the Dhaka Building Construction Rules 2008, which introduced the Floor Area Ratio (FAR) concept. The FAR was determined based on the road width and plot size. The rule mandated that a certain percentage of the plot must be kept as open space; hence the practice of Maximum Ground Coverage (MGC) was introduced, and it was between 50% to 67.5%, depending on the plot size. The larger the plot size, the smaller the building footprint. The introduction of FAR increased the amount of open space in the neighbourhood, and the height variation was found in the buildings. The rule also allowed for different densities in different city areas, developing more planned and organized neighbourhoods.

The recent DAP (Detailed Area Plan 2022-35) [1] for Dhaka has proposed an area-based FAR (Floor Area Ratios) as a part of the building regulations. In the previous Dhaka Metropolitan Building Construction Rules, 2008, FAR was decided based on the front road width and plot sizes without fully considering the surrounding context, land use, or accessible civic facilities. This would unnecessarily increase the area's population density without sufficient infrastructure to support the growth. The recent FAR regulations of 2022 intend to address these limitations by determining the FAR based on existing population density, road characteristics of an area. However, before the rules are applied, it is essential to verify how the new building regulations will impact the microclimate and environment of the city. Our study aims to

Table 1: FAR and MGC rules, Dhaka Building Construction Rules 2008

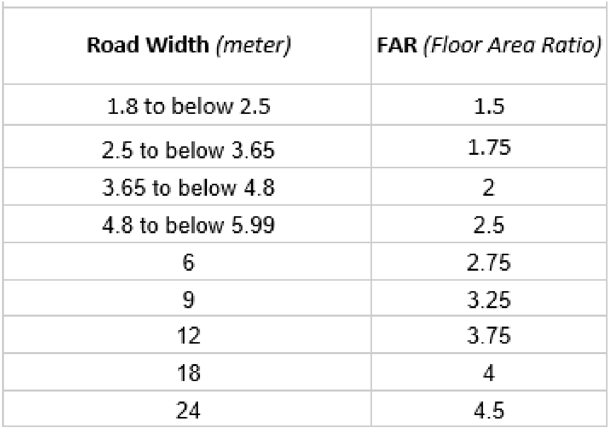


Building Function	Plot Size *(Khata)* *1 katha = 720 sft*	Road Width *(meter)*	FAR *(Floor Area Ratio)*	MGC *(Maximum Ground Coverage)*
Residential	2	6	3.15	67.5
Residential	3	6	3.35	65
Residential	4	6	3.5	62.5
Residential	5	6	3.5	62.5
Residential	6	6	3.75	60
Residential	7	6	3.75	60
Residential	8	6	4	60
Residential	9	6	4	60
Residential	10	6	4.25	57.5
Residential	12	9	4.5	57.5
Residential	14	9	4.75	55
Residential	16	9	5	52.5
Residential	18	9	5.25	52.5
Residential	20	9	5.25	50
Residential	21 and above	12	6	50

propose a new methodology to create an automated system to generate 3D building geometry for both existing and future scenarios to test the implications of various design options on urban microclimate.

The DAP recommends the development of buildings as block-based land redevelopment schemes where building height will be determined by the amount of area left open which must be used as fields, playgrounds, or parks without any covering on top. There will be no height limit for buildings constructed in a block larger than five acres where 60 percent of space is left open. According to the new DAP, the planned areas will benefit from higher FAR than the unplanned areas, and the latter will need to leave more open spaces around the building.

Table 2: Plot-based FAR rules for Residential Building, DAP 2022-2035



Road Width *(meter)*	FAR *(Floor Area Ratio)*
1.8 to below 2.5	1.5
2.5 to below 3.65	1.75
3.65 to below 4.8	2
4.8 to below 5.99	2.5
6	2.75
9	3.25
12	3.75
18	4
24	4.5

Table 01 and 02 presents the information considered while designing the FAR 2008 and 2022, respectively. For example, before the FAR regulations were established, Dhanmondi used to have a 6-floor height restriction with a fixed setback around the building. The plot sizes were bigger, like 10 katha to 20 katha (1 katha is equal to 720 square feet), which were subdivided by the owners in the subsequent years. With the introduction of FAR in 2008, building heights and setbacks were determined by the plot sizes and front road width. In the new FAR in 2022, more restrictions are applied on the basis of population and building density, and public facilities. The DAP 2022-2035 divides Dhaka, one of six regions, into 27 sub-regions. Dhaka Structure Plan (DAP) 2022-35 proposes two types of FARs. One is based on road width, and another is based on the location of the plot, but we need to consider the lower value of the Two, and MGC will be considered according to the Dhaka Building Construction Rules, 2008. The location-based FAR differs significantly in different areas. For example, in Dhanmondi Ward-15 the Area FAR is 5.1, but in Shenpara Porbata it is 2.6, where it was 3.76 according to the FAR 2008 rules. However, there are some incentives based on population density, and the proposed rule aims to decrease building heights and population densities to ensure the city remains liveable and sustainable.

To examine the environmental performance of future scenarios, it is important to build the 3-D model as per the building regulations. So far, no such modelling approach exists for the FAR regulations in Dhaka. Data availability is another issue in such context. Although GIS data exists for the existing built-environment, the data is not open source and not available for the whole metropolitan area, particularly for those areas occupied by the military for obvious security reasons.

Urban planners and architects must often create 3D models of metropolitan areas that conform to local building codes. However, this time-consuming and error-prone process can be difficult to automate. Existing tools for creating 3D models of urban areas are often based on manual input or simplified assumptions that do not reflect the complexities of building codes and other regulations. This can result in models that are inaccurate, incomplete, or non-compliant with regulations. However, some plugins for grasshopper are also working with GIS files, and it will load the whole file area, which causes the computing process to slow; besides, it will work only for modelling existing data.

The workflow we have developed can model 3d buildings for two different conditions. One is modelling from GIS data, and another is from the outline of plots where no GIS files are available yet. For the former condition, we need to pre-process the GIS data in a separate software and export all metadata of the study area from the whole dataset as a *.csv format. Therefore, the 3d modelling and simulation phase based on existing conditions becomes very fast for further process. And for both cases, we can create a detailed and accurate 3D model of an urban area that conforms to the FAR rules of local building codes. This allows the exploration of parametric models and automates repetitive tasks and can compare the legal situation with existing scenarios. In addition, we can visualise other geometric data regarding mandatory open space, setbacks, and vegetation models of the study area. The workflow provides a novel and automated approach to creating 3D models at the urban block level that can potentially improve the accuracy and efficiency of urban planning and architecture.

The urban microclimate refers to the local atmospheric conditions within a city or urban area which is influenced by a variety of factors including the configuration of the urban morphology [2][3]. Improper arrangement of buildings can lead to the urban heat island (UHI) effect further aggravating the heat waves affecting people's health [4], building energy performance [5] as well as the economy [6]. Therefore generating accurate microclimate information for unbuilt morphological scenarios is crucial to mitigate the adverse effects of UHI and heat waves in dense urban areas. However, despite significant advancement in urban microclimate simulation (UMS) tools in recent years, there are only a few tools such as Urban Weather Generator (UWG) [7] that allow a quick estimation of the UHI effect in the urban canopy for decision-making processes. The UWG has been demonstrated to have the ability to generate weather files that are specific to a particular neighborhood at a reasonable computational cost. This process involves using meteorological data from a nearby rural weather station, as well as incorporating the typical characteristics of the urban area. The parametric modelling capability in UWG makes it particularly suitable for the current study, by comparing various morphological options using the current and past building regulations.

Methodology

Case Study Area: The case study areas for this study are based in Dhanmondi (*see Figure 2a)*) and Purbachal (*see Figure 2b*). Dhanmondi is one of the most built-up areas in the city which is predicted to be benefitted from the FAR-2022 regulations. Initially, most plots in the area were 20 Katha in size. However, later on, plot division was limited to no less than five katha, and the maximum number of floors was restricted to six stories. As a result, for a significant duration of time, this region was developed in accordance with various building construction regulations. The other case study area is Purbachal where large land expansion is occurring to create more housing provisions for the city. Since the area is still unbuilt, it gives an opportunity to examine the impact of FAR regulations in full effect.

Workflow: The study presents an automated workflow (*see Figure 1*) to generate the existing and future building geometries based on FAR regulations in Dhaka. Existing buildings are generated from GIS-based data. First, in order to extract the specific GIS data for the study area, we have developed an independent interface in Python and GUI (Graphical User Interface) – an open-source library for interface design using PY-QT.

For generating the future building scenarios, a Grasshopper (GH)-Python algorithm is designed in the Rhino-Grasshopper platform. In this stage, we create the 3D using actual information on building heights, road properties, and surface cover extracted from the GIS data. Following the FAR regulation and GIS land use data (plot area), we apply the FAR algorithm mentioned above for future building scenarios. Any changes in FAR rules that can be applied in the building/ urban geometry can be easily applied through the algorithm.

Urban Weather Generator: In the next stage, we apply an Urban Weather Generator (UWG) model to examine the environmental/ microclimate changes that will occur with applying the FAR rules. UWG is a tool to calculate environmental parameters inside urban canyons either from weather station data or TMY (typical meteorological year) data usually accessed from the Energy Plus [8] in EnergyPlus Weather File (EPW) Format. Our study area was focused on the residential area to avoid the complexity of the model. For the Dragonfly (DF) Assign Building UWG Properties, the wall and the roof albedo were 0.30 and 0.10, respectively, on a scale of 0-1.0, and the window-to-wall ratio parameter was 0.30. The watts per area value for the DF Traffic Parameters was 20 W/m2. Both the vegetation albedo in the urban area and vegetation cover of the reference EPW site was 0.25 on a scale of 0-1.0.

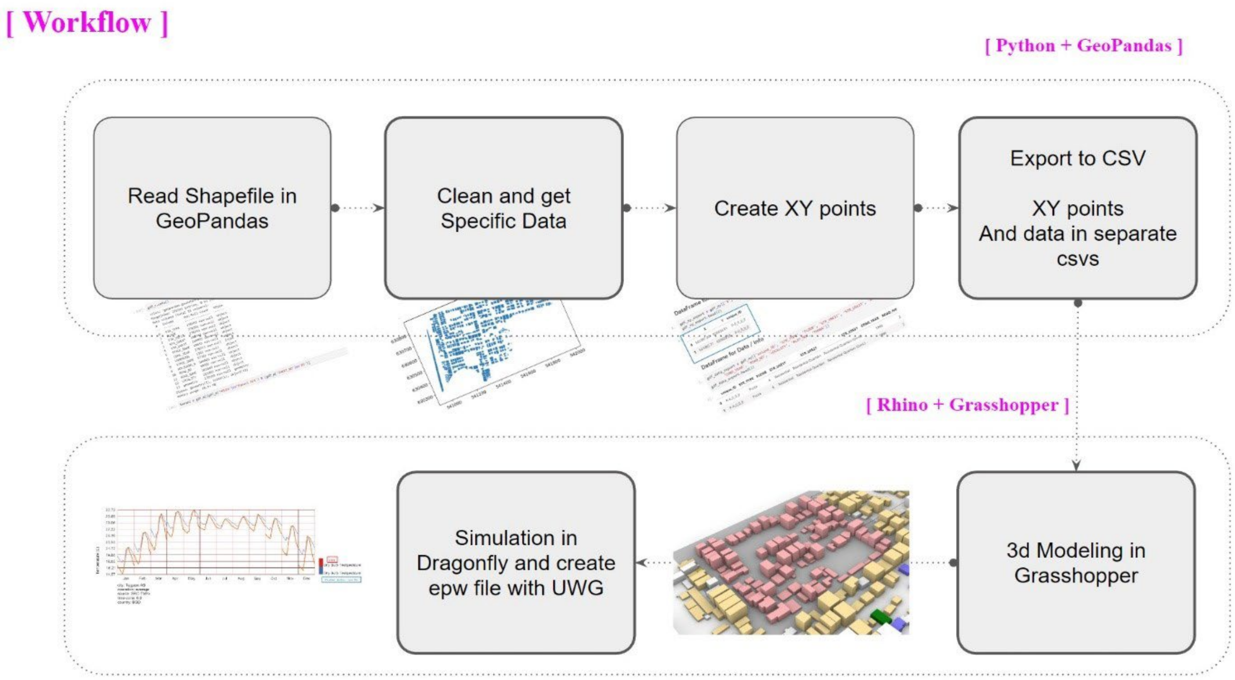


Figure 1: Workflow showing the steps of the methodological framework

We have examined seven scenarios in UWG, which are explained below:

Modelling scenarios:

Scenario 1: No FAR_1996, this is a hypothetical scenario where all buildings are extruded to the maximum allowable height of 6 stories (for the Dhanmondi area) according to the National Building Regulation of 1996 until the FAR regulation came into effect in 2008. In this scenario, there were no requirements for leaving out permeable open surfaces and trees. The only mandatory open space was rear and side setbacks between 1.25 – 3.0 meters, depending on the plot size. Therefore, a treeless situation represents many built-up areas in Dhaka. *(See Figure 2c).*

Scenario 2: Existing Building Model (RAJUK 1996 and FAR-2008), This scenario represents the actual and existing built-environment situation with buildings constructed under the FAR-2008 regulations, along with buildings built previously. The existing scenario is based on GIS data, including building type, land use, number of floors, and construction year. Tree modelling was automated based on an algorithm determined as 50% of the empty area within a plot. *(See Figure 2d)*

Scenario 3: Introduced FAR-2008 (FAR-2008), this is a hypothetical scenario where all buildings are built according to the Far-2008 regulations. The permeable surface cover has been calculated from the regulations with the option of trees in the front of each building. *(See Figure 2e)*

Scenario 4: FAR-2008 no tree (FAR-2008_NT), it is the same scenario as Scenario 3 but without trees and grass cover. This is the closest growth pattern in the current built-environment situation in Dhaka, where there is very little vegetation or trees visible in urban areas. *(See Figure 2f)*

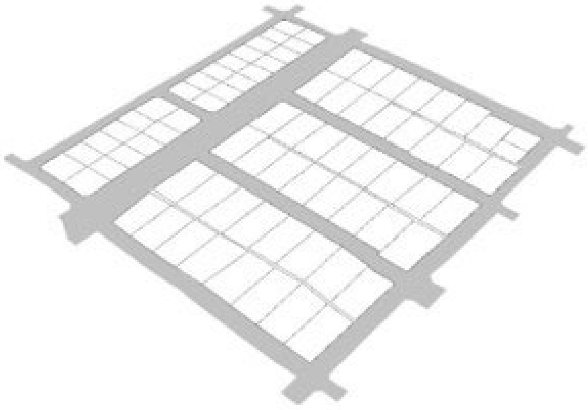
Scenario 5: New FAR-2022 (FAR-22); this is also a hypothetical scenario where all buildings are built according to the Far-2022 regulations. In this model FAR 5.1 was the limit. Therefore, many buildings need to be developed in considering FAR 5.1, even if there are 25% of plots were above FAR 5.1, but the according to the MGC rules, it remains the same. Hence, the main difference between Scenario 3 and Scenario 5 is the total floor area which reduces the building height and the number of occupants. *(See Figure 2g)*

Scenario 6: New FAR-2022 no tree (FAR-22_NT); it is the same scenario as Scenario 5 but without trees and grass cover. *(See Figure 2h)*

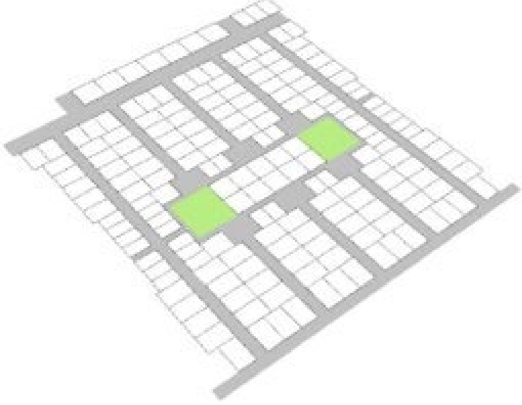
Scenario 7: FAR-2022 unbuilt area (FAR-22_UA) represents a new development area called Purbachal, where a large land expansion is occurring in Dhaka. *(See Figure 2i)*

Results

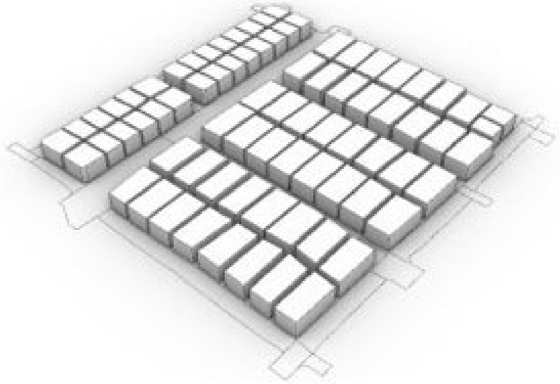
In all cases, Scenario_1 shows the highest dry-bulb temperature (DBT) and lowest relative humidity (RH) The mean DBT for whole year shows Scenario_1 has the highest DBT of 27.33^0C and Scenario_2 has the lowest 27.17^0C. Since Scenario_1 has no trees and vegetation and a Building Surface Fraction (BSF) of 80%, compared to Scenario_2 which has some vegetation and trees and a BSF of 50%, a noticeable difference is expected between the two scenarios in terms of DBT and RH. BSF refers to the proportion of land surface covered with buildings (the building footprint) in relation to the total ground surface, expressed as a percentage [9]. No difference is observed between Scenario_3, 4 and Scenario_5, 6 as the values are generated for the whole area rather than individual streets



a) Block Characteristics of Dhanmondi

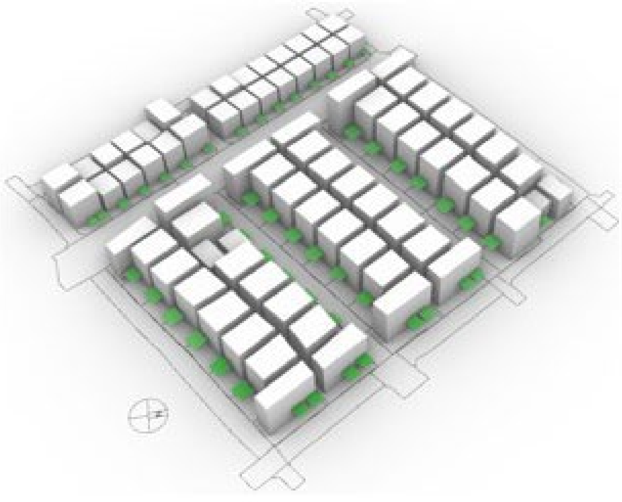


b) Block Characteristics of Purbachal

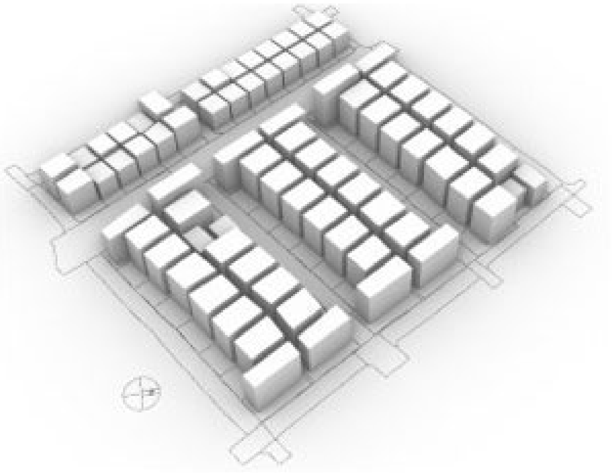


c) Scenario_1: Rajuk Rule 1996, Dhanmondi

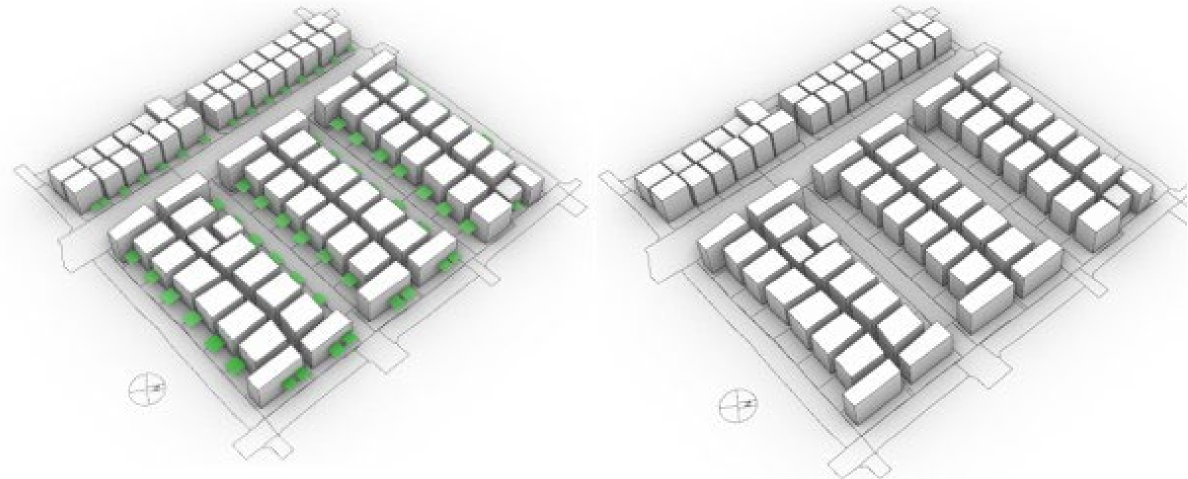
d) Scenario_2: Existing built area, Dhanmondi



e) Scenario_3: FAR rule 2008, Dhanmondi



f) Scenario_4: FAR rule 2008, Dhanmondi, No Tree situation



g) Scenario_5: FAR rule 2022, Dhanmondi

h) Scenario_6: FAR rule 2022, Dhanmondi, No Tree situation

i) Scenario_7: FAR rule 2022, Purbachol

Figure 2: Algorithmic based auto generated 3d urban modelling for different scenarios of the study area.

Table 3: Mean Dry Bulb Temperature (DBT) in different scenarios

	Scenario_1	**Scenario_2**	**Scenario_3**	**Scenario_4**	**Scenario_5**	**Scenario_6**	**Scenario_7**
	1996_noTree_DBT	*Existing Model_veg_DBT*	*FAR-2008_tree_Veg_DBT*	*FAR-2028_NoTree_Veg_DBT*	*FAR-2022_Veg_DBT*	*FAR-2022_NoTree_Veg_DBT*	*FAR-2022 unbuilt_DBT*
Mean DBT (Whole year)	27.33	27.17	27.27	27.27	27.24	27.24	27.2
Mean DBT *(Winter_January)*	19.83	19.7	19.76	19.76	19.74	19-74	19.72
Mean DBT *(Summer_May)*	30.32	30.17	30.28	30.28	30.25	30.25	30.2
Mean DBT *(Monsoon_Aug)*	29.59	29.43	29.54	29.54	29.51	29.51	29.46

Table 4: Mean Relative Humidity (RH) in different scenarios

	Scenario_1	**Scenario_2**	**Scenario_3**	**Scenario_4**	**Scenario_5**	**Scenario_6**	**Scenario_7**
Mean RH *(Whole year)*	68.32	68.94	68.53	68.53	68.63	68.63	68.82
Mean RH *(Winter_January)*	65.79	66.33	66.07	66.07	66.13	66.13	66.24
Mean RH *(Summer_May)*	72.50	73.12	72.69	72.69	72.80	72.80	72.99
Mean RH *(Monsoon_Aug)*	80.57	81.31	80.79	80.79	80.92	80.92	81.15

or precise positions where at a finer resolution greater differences in DBT and mean radiant temperature (Tmrt) will be visible. Scenario_7 has slightly lower DBT, and higher RH compared to Scenario_3,4 and Scenario_5, 6 because of its higher vegetation and open spaces. In a similar study analysing the impact of urban morphology and building energy load using UWG, Kamal et al. [10] reported that increased building footprint density could increase cooling consumption. They also reported that increase in greenery was unsuccessful in saving energy as can be seen in our Scenario_3, 4, 5 and 6 (*See Table 3 and 4*).

The DBT profile was observed for the hottest day in the year on 19 April for a 24-hour period (*see Figure 3*). The profile is similar for all scenarios, with the lowest temperature reaching just before sunrise (6 am) and reaching the highest temperature around 4 pm. An urban heat island (UHI) effect is visible in Scenario_1 from 6 pm and a difference of 0.3-0.4^{0}C between Scenario_1 and Scenario_2.

We also observed the DBT on Oct. 28 (*see Figure 4*) when the highest difference of 0.5^{0}C was observed among the scenarios. Again, the highest difference was found between Scenario_1 and Scenario_2, mainly after the sunset at 6 pm. After sunset, Scenario_3, 4, 5, 6, and 7 show almost similar values.

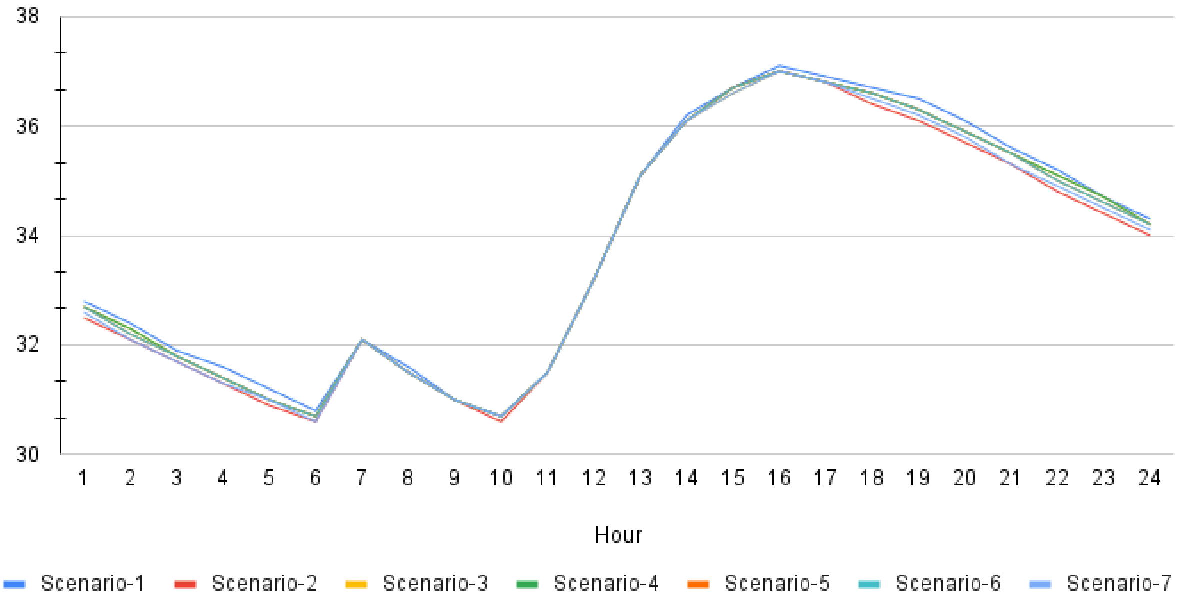


Figure 3: Air temperature profile on 19 April, Hottest Day

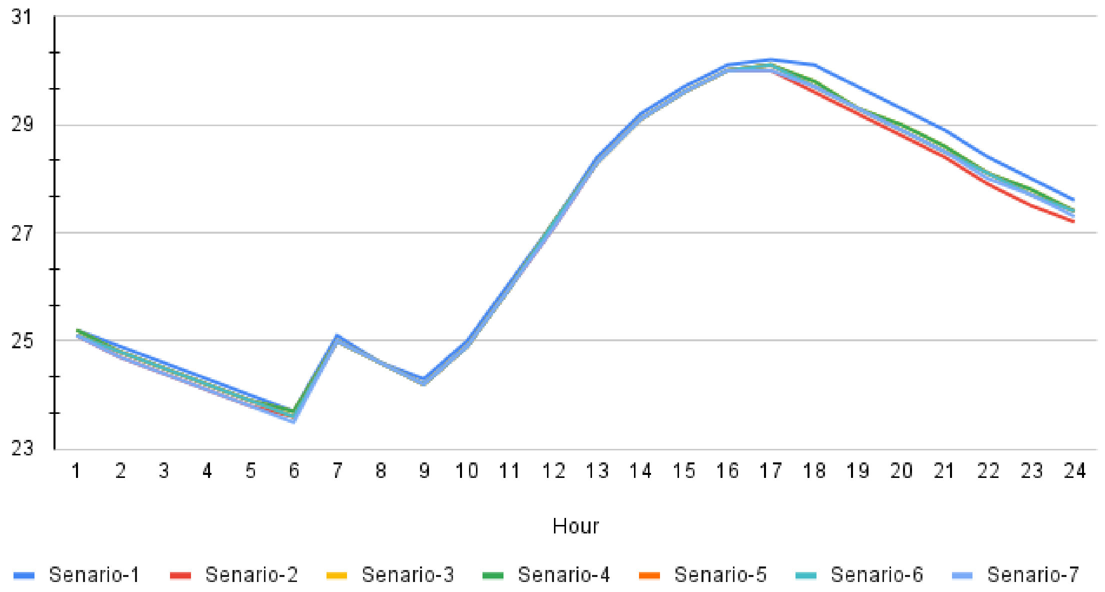


Figure 4: Highest difference between scenarios observed on 28 October

Conclusion

The novelty of this work lies in creating a seamless workflow to generate 3-dimensional models/geometry for urban areas where the information is not readily available. The workflow has developed an algorithm to generate future urban morphology following the building regulations, in this case, FAR-2022 regulations for Dhaka. This automated process of 3-D modelling will enable the urban planners and designers to compare the environmental performance of various design options using available environmental simulation tools such as UWG. In this study, we have found that the introduction of FAR may have stopped further environmental degradation, which could have happened with the continuation of the Building Regulations 1996. The Building Regulations 1996 only proposed set-back rules and height restrictions without considering protecting the green areas and permeable surfaces within the building plot. The situation has been improved since the area-based FAR 2022 rule was set as a limit, therefore in spite of having the same open space and vegetation area, it reduces the floor area and the number of inhabitants in the same location. However, in the newly developed area like Purbachal, we found a better situation since there are dedicated public open spaces for vegetation and greenery besides mandatory open space for each plot.

Reference

[1] RAJUK, "The Detailed Area Plan (DAP)," Dhaka, 2022.

[2] T. Sharmin, K. Steemers, and A. Matzarakis, "Analysis of microclimatic diversity and outdoor thermal comfort perceptions in the tropical megacity Dhaka, Bangladesh," *Build. Environ.*, vol. 94, pp. 734–750, 2015.

[3] J. Littlewood, R. Howlett, and L. C. Jain, *Sustainability in Energy and Buildings*. 2009.

[4] D. Ghatak, B. Zaitchik, C. Hain, and M. Anderson, "The role of local heating in the 2015 Indian Heat Wave," *Sci. Rep.*, vol. 7, no. 1, pp. 1–8, 2017.

[5] J. Tan et al., "The urban heat island and its impact on heat waves and human health in Shanghai," *Int. J.* Biometeorol., vol. 54, no. 1, pp. 75–84, 2010.

[6] Y. Xia et al., "Assessment of the economic impacts of heat waves: A case study of Nanjing, China*,*" *J. Clean. Prod.*, vol. 171, pp. 811–819, 2018.

[7] B. Bueno, L. Norford, J. Hidalgo, and G. Pigeon, "The urban weather generator," *J. Build. Perform. Simul.*, vol. 6, no. 4, pp. 269–281, 2013.

[8] EnergyPlus, "Weather Data," 2023. [Online]. Available: https://energyplus.net/weather.

[9] M. U. Cilek and A. Cilek, "Analyses of land surface temperature (LST) variability among local climate zones (LCZs) comparing Landsat-8 and ENVI-met model data," *Sustain. Cities Soc.*, vol. 69, no. October 2020, p. 102877, 2021.

[10] A. Kamal et al., "Impact of urban morphology on urban microclimate and building energy loads," *Energy Build.*, vol. 253, p. 111499, 2021.