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Introduce Climate-Sensitive Building Codes to Reduce Urban Density And Encourage Sustainable Urban Growth

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ABSTRACT

The study focused on assessing the attributes of traditional urban houses, in dense cities such as Dhaka, that reduced urban density and catered to sustainable urban growth, to introduce climate-sensitive building codes. Dhaka being the capital of Bangladesh is expanding rapidly with minimal space for urban green and community interactions. Dhaka building code does not fully solve the issue of sustainability and density unlike the fine grain traditional buildings of old Dhaka with its climate-sensitive courtyard houses. The Rajdhani Unnayan Kartripakkha (RAJUK) approves building permits based on floor area ratio, maximum ground coverage, setback, fire safety, parking provisions, room dimensions, specific requirements on a case-to-case basis and based on the area and its special features; but the climate-responsive steps in building codes is completely missing till now unlike those practiced in traditional urban houses. This study aimed at assessing the factors of climate-sensitive traditional urban houses which minimized urban density and catered to sustainable urban growth to introduce climate-sensitive building codes to reduce urban density and encourage sustainable urban growth. The research methodology adopted a mixed method approach. Attributes that contribute to reducing urban density and encouraging sustainable growth were identified through literature review and evaluated by field observation. The case studies selected, for qualitative research, are a multistoried traditional urban residence in Panam City and a modern residential apartment in Dhaka which was designed maintaining building codes and acts. The quantitative method included measuring the climate-sensitive aspect of courtyards through Rhino and Grasshopper; and assessing the perceptual density of the street, proposed with modern courtyard buildings, through questionnaires. Key findings indicated that many climate-sensitive features from traditional urban dwellings can be incorporated into new building codes to reduce urban density. Finally, the study proposed possible climate-sensitive building codes aimed at reducing urban density and encouraging sustainable urban growth.

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1. Introduction

Traditional buildings of Bangladesh in both rural and urban context provided passive climate-sensitive solutions in terms of shading from rain and sunlight, controlling indoor room temperature and natural ventilation, and accommodating interactive spaces for social transactions. The traditional facades were climate-sensitive in their choice of architectural elements such as shading devices and screens, materials, textures, and colors to secure themselves from natural elements. In the past crucial spatial elements were borrowed from rural vernacular buildings, such as the courtyard, by traditional urban buildings. Modern buildings of Dhaka contradict these traditional architectural and spatial elements as it is a matter of choice due to the existing local building codes. The indoor comfort of modern buildings is suffering due to uncontextual and McDonalized building elements. Also, the modern buildings disregard the need for elaborate social spaces, such as the courtyard, that once aided in reducing urban density. Hence the need to reinvent traditional architectural and spatial elements through building codes is of paramount importance to reduce urban density and encourage sustainable urban growth.

The key research questions are; what are the climate-sensitive architectural and spatial attributes of traditional buildings that aided to reduce urban density; how to introduce climate-sensitive building code/codes for modern buildings to reduce urban density and encourage sustainable urban growth. The research aims to introduce climate-sensitive building code/codes to reduce urban density and encourage sustainable urban growth. To achieve the research aim, two objectives have been formulated based on the research questions. The two objectives of this research are to identify the climate-sensitive architectural and spatial attributes of traditional buildings that aided to reduce urban density, and to introduce climate-sensitive building code/codes for modern buildings that will reduce urban density and encourage sustainable urban growth. The research scope is to establish a way forward to analyze existing building codes for their climate-sensitive properties and characteristics to reduce urban density.

1.1 Research Problem

According to UNEP [31] 1.6 billion urban dwellers will get exposed to high temperatures regularly by 2050. GlobalABC [32], states that the major contributor to climate change are buildings and the construction sector as they release 21 per cent of global greenhouse gas and in 2022 buildings accounted for 34 per cent of global energy demand and 37 per cent of energy and process-related carbon dioxide emissions. UNEP [31] also states that the impacts of climate change such as heat waves will affect the built environment and society. The Rajdhani Unnayan Kartripakha (RAJUK) approves building drawings for construction by assessing its floor area ratio (FAR), maximum ground coverage (MGC), setback, fire safety, and parking provisions based on the site area and its special features if any, its room dimensions, and in exceptional situations specific requirements are given on a case-to-case basis. It is seen in many circumstances that these building acts and laws are at times thoroughly misinterpreted and abused by profit making real estate companies offering similar spatial solutions for any context. The traditional urban houses were climate-responsive with certain spatial features that reduced urban density, but the significance and applicability of their traditional features are not always found in the current building codes. Consequently, most modern urban residential neighborhoods in Dhaka are facing high urban density, inadequate social spaces for interaction, an overall decline in thermal comfort and limited unshaded green space for rainwater absorption. According to BNBC [4], fifty percent of the mandatory open space in a plot, under section 1.8.8 and 1.8.9, can be used for construction of garage, ramps, caretaker or guard room and other auxiliary services required for the building; provided the building is not more that 33m or ten-storeys high. But it is seen in many cases that the ground floor and/or basement is taking up a hundred percent of the site leaving no green for water absorption. The modern urban facades of residential apartments, used mostly by nuclear families, is obsessed with meeting trendy requirements such as designing small, attached terraces/ verandas for each proposed bedroom. Whereas traditional urban houses had a bigger gathering space/ one large veranda/ terrace/ courtyard for social gatherings, to act as buffer space, and for adequate ventilation which catered to interior thermal comfort. The urban form of traditional urban buildings, due to presence of these climate-sensitive spatial elements, rendered the neighborhood perceptually less dense. The traditional street frontages, due to the characteristics of the traditional urban form, had human scale spaces for social interactions.

2.0 Reducing Urban Density to encourage Sustainable Urban Growth by introducing Climate-Sensitive Building Codes

The building code is a crucial method to incorporate climate-sensitive practices in building designs to reduce urban density and consequently encourage sustainable urban growth.

2.1 Urban Density

According to Ng [24] there are two categories to measure physical density which are population density and building density; population density is the ratio of people or households and given area, and building density is the ratio of building structures and an area unit.

According to Shlomo *et al.* [2], urban density is usually measured as the ratio of the total city population and its total area. Shlomo *et al.* [2] also states that it is the most appropriate metric for measuring densification progress in cities and is a central objective of the global climate change agenda. According to several authors, [3,19 and 25] urban density is the ratio of total population and urban footprint. Ramachandra, and Sowmyashree [27] states that, urban footprint is measured through the quantification of paved surface (land required by urban metabolism processes, and waste assimilation systems) used by human. According to Shlomo *et al.* [2], urban footprint is the “total contiguous built-up area of the city and its urbanized open space”.

2.1.1 Perceptual Urban Density

According to Ng, [24] density can be defined by both physical forms and non-physical aspects such as perceived density. Dempsey, N. *et al.*, [13] states that density is also closely related to the social environment configuration and interaction within residential neighbourhoods. Dempsey, N. *et al.*, [13] states that there is a cultural dimension to density, as the densities of where people live may be considered as relative. For example, DCLG [12] mentions that English housing policy states that new residential building should be at least 30 dwellings/ha which is high density for some but Jenks [20] mentions that in Hong Kong ten times that density would be considered low.

According to Churchman [10] Density is a complex concept with inter-related dimensions providing both objective (spatially based, measure of the number of people in a given area) and subjective measures (such as a social interpretation dependent on individual characteristics which may vary from resident to resident).

Beatrix [8] states that urban environments which accommodate numerous people and still retains a pleasant atmosphere are likely to be successful. In an interdisciplinary project led by Beatrix [8], funded by the ETH Career Seed Grant, it was examined how individuals perceive urban density. Beatrix [8] opines that floor area ratio (FAR) indicates how any project will fit within existing urban density of its location, but it does not measure how people may perceive the density. The survey led by Beatrix [8] revealed that participants of the study reported four factors to be crucial for their judgment on density they are number of visible buildings, building height, visibility, and presence of green spaces. The number of visible buildings was the most vital factor when judging the perceived urban density.

2.1.2 Urban Density in BNBC 2020 and DAP (2022 to 2035)

According to BNBC [4] housing density for an area, locality or settlement will be in accordance with Detail Area Plan (DAP). According to DAP [11] Gross density is the population per acre and Net density is family per Katha. In any area if non-residential land use such as roads, parks, playgrounds, water bodies, civic amenities etc. is adequate, then the Gross density of the area will be low even if the net density is high. Two crucial factors that affect gross density of an area are net non-residential land use of a particular area (%) and total area (sqft) of residential units of a particular area; these two factors decide the floor area ratio (FAR) and total floor space of each area.

2.1.3 Attributes of Urban Density

Soltani *et al.* [30] demonstrated through their research that the method used to measure density in census data and statistical studies, people per hectare (p/ha), does not represent factors of design and does not illustrate about specific configurational or morphological attributes. Soltani *et al.* [30] opined, that various design factors can influence density such as morphological characteristics of individual buildings, block types and design attributes of street networks. According to Soltani *et al.* [30] the same building density can synthesize various design layouts. Hamaina *et al.* [17] stated that existing methods mostly skip exploring density relative to spatial relationships and arrangements of the building and street networks. Zainol and Elsawa [34] opined that streets and building forms can be arranged to take benefits from density, such as analysing how various densities affect access to integral facilities, public transport, infrastructure, health services, etc. Grosvenor and O'Neill [15] opined that conventional density measurements do not adequately include the structure of the built form and variations in accessibility and location. Soltani *et al.* [30] mentions that conventional density measurements also disregard spatial features of the given area. Berghauser Pont and Haupt [9] introduced the Spacemate matrix, projecting various intensity, compactness, and the network density of many cases. Spacemate matrix, combines Ground Space Index (relation between built and open space), Open Space Ratio (pressure on non-built space) and height with Floor Space Index (Floor Area Ratio) of an area and considers a density network, to synthesise an index for density distribution.

According to Shlomo *et al.* [2], Urban density is a product of three or seven factors, and it has been illustrated in two formulas; Floorspace occupancy × floor area ratio × residential share = urban density and Dwelling unit occupancy × occupancy rate × dwelling unit packing × floor plan efficiency × building height × plot coverage × residential share = urban density. Shlomo *et al.* [2] opined that the results of the above may have substantial errors, but they still prove that variations exit in the calculation for density among cities and that different factors influence urban density. Shlomo *et al.* [2] through their research demonstrated that, even if a city has a relatively high urban density, it does not always imply that attributes influencing urban density all have above-average values and vice versa. For example, Shlomo *et al.* [2] mentions that Dhaka has high urban density from its above-average floorspace occupancy and its above-average residential coverage, even though it has below average floor area ratio.

2.1.3.1 Attributes of Urban Density that affect Thermal Comfort

According to Churchman [10], the density of cities is related to topics such as, environmental quality, transportation systems, physical infrastructure and urban form, social factors, and economic factors which impacts quality of urban life. According to Wei *et al.* [33], attributes of building density give character to urban morphology and that these attributes have a crucial relation with the outdoor thermal comfort variables. Wei *et al.* [33] opined that building density has a strong influence on the microclimate. Efrita *et al.* [14] states that Ratio of gross floor area to site plan area (FAR), Ratio of footprint area to site plan area (BCR), and the ratio of the width to the height of the building (Aspect

Ratio) and Ratio of open space area to site plan area (OSR) are the attributes of building density which have effect on climate factors such as air temperature (Ta), mean radiation temperature (Tmrt), and relative humidity (RH).

Efrita *et al.* [14] *in their research stated that* building density influences the outdoor thermal comfort; as the ratio of gross floor area to site plan area increases, when ratio of footprint area to site plan area remains constant, air temperature and mean radiation temperature get higher. They also stated that when ratio of footprint area to site plan area increases, as the Ratio of gross floor area to site plan area is constant, air temperature, mean radiation temperature, and relative humidity will also increase. They also stated that a green open space is needed with appropriate pavement material to establish outdoor thermal comfort.

Su and Antoni [29] states that Urban densities affect the pedestrian thermal environment. In their research they found that urban densities are affected by attributes such as the ratio of building heights to street width (H/W) and sky view factor (SVF). Su and Antoni [29] also states that thermal comfort was dependent on wind speed, as wind speed influences subjective thermal comfort. According to Mahmoud [23] sky view factor and wind speed affect outdoor thermal comfort directly. Su and Antoni [29] in their research opined that tall buildings provide shading and stronger wind around the corners and displayed through analysis that buildings with higher ratio of building heights to street width and lower sky view factor provide more outdoor thermal comfort. Berardi and Wang [7] also states that taller building in urban areas have wind acceleration around the corners. Su and Antoni [29] states that in humid-subtropical climate high thermal comfort can be achieved by lowering radiation and air temperature, and accelerating wind speed can also improve thermal comfort and improve urban ventilation. Refer to Table 1, it is a Summary of Attributes of Urban Density mentioned in 2.1. 2.1.1. 2.1.2, 2.1.3 and 2.1.3.1.

Table 1
Summary of Attributes of Urban Density

Attributes of Urban Density (Physical/ Objective Measures)	**Attributes of Perceptual Urban Density (Non-Physical/ Subjective Measures)**	**Attributes of Urban Density that affect Thermal Comfort (Physical/ Objective Measures)**	**Urban Density in BNBC 2020 and DAP** **(Physical/ Objective Measures)**
Ratio of the total city population and its total area Ratio of the total population and urban footprint. People per hectare (p/ha),	Social environment configuration and interaction within residential neighborhoods	Urban morphology	Gross density is the population per acre Net non-residential land use of a particular area (%) Total area (sqft) of residential units of a particular area; These two factors decide the floor area ratio and total floor space of each area.
Configurational or morphological characteristics of individual buildings,	Cultural dimension to density, as the densities of where people live may be considered as relative	Ratio of gross floor area to site plan area (FAR)	Net density is family per Katha.
Structure of the built form	Social factors, and economic factors	Ratio of footprint area to site plan area (BCR)	

Spatial features	Visible buildings, building height, visibility, and presence of green spaces.	Ratio of the width to the height of the building (Aspect Ratio)	
Block types,		Ratio of open space area to site plan area (OSR)	
Design attributes of street networks		High Ratio of building heights to street width (H/W)	
Spatial relationships and Arrangements of the building and street networks		Low sky view factor (SVF).	
Access to integral facilities, public transport, infrastructure, health ervices,		Tall buildings provide shading and stronger wind around the corners	
Transportation systems,		**Attributes of Urban Density that affect Thermal Comfort (Non-Physical/ Subjective Measures)**	
Physical infrastructure and urban form,		Environmental quality	
Compactness, network density of many cases		Microclimate	
Ground Space Index (relation between built and open space),		Wind-speed, influences subjective thermal comfort.	
Open Space Ratio (pressure on non-built space)		Accelerating wind speed	
Height with Floor Space Index (Floor Area Ratio) of an area		Lowering radiation and air temperature	
Floorspace occupancy × floor area ratio × residential share = urban density		Environmental quality	
Dwelling unit occupancy × occupancy rate × dwelling unit packing × floor plan efficiency × building height × plot coverage × residential share = urban density.		Microclimate	

Source: adapted from, James (1967), Churchman (1999), Dempsey, Jenks (2000), DCLG (2006), Berghauser Pont and Haupt (2007), N. et al., (2010), Mahmoud, A.H.A (2011), Ramachandra and Sowmyashree, (2012), Hamaina, Leduc, and Moreau (2014), Grosvenor and O'Neill (2014), Ng (2014), Angel et al. *(2016), Wei et al. (2016), OECD (2018), Zainol and Elsawa (2018), Beatrix Emo, Soltani et al. (2020), Shlomo et al. (2021), Berardi, U. and Wang, Y. (2021), Efrita Nur Widiyannita* et al. (2021), *Su Y-M and Antoni J. (2023), BNBC 2020, DAP (2022 to 2035) by authors, 2024*

2.1.4 Reducing Urban Density and its Relevance to Sustainable Urban Growth

According to Hess [18] urban density illustrates any city's level of compactness of people or development. Shlomo *et al.* [2] states that in a compact city population is in a smaller geographical footprint and movement between places is efficient; hence, in terms of both land consumption and transportation a more compact city will become a more sustainable city. When Urban Density is reduced by climate-sensitive building codes then both density and climate is being addressed which will also harness Sustainable Urban Growth.

2.2 Climate-Sensitive Building Codes and Urban Density Reduction

Climate-sensitive building codes that will reduce urban density can be incorporated.

2.2.1 Climate-Sensitive Building Codes in BNBC 2020

BNBC [4-5] comprises of three volumes (I, II(A), II(B) and III) and eight parts, of which no chapter is dedicated exclusively to climate-sensitive codes. Rather some chapters of Part III of Volume I titled, “General Building Requirements”, Control and Regulation and Part VIII of Volume III titled, “Building Services” provide ways to address natural elements and protect surrounding environment. Hence designs are expected to be climate-sensitive and sustainable if these codes are followed accordingly.

2.2.1.1 Climate-Sensitive Building Codes in BNBC 2020, Volume I, Part III

BNBC [4], Chapter 1 of Part III comprise of codes for general building requirements. Some of these codes address climate and environment through codes for land use classification, requirements of plots, open spaces within a plot, community open space and amenities, landscaping, damp-proofing and waterproofing, ventilation, lighting and sanitation, thermal insulation, lightning protection of buildings, rat proofing and termite proofing of buildings, requirements for buildings in flood prone and coastal regions of Bangladesh and requirements for buildings in other disaster-prone areas. Chapter 3 of Part III include codes for classification of building construction types based on fire resistance. Some of these codes are also associated with climate and the environment which includes codes on weather protection, projections (sunshades, cornices, projected balconies, and overhanging), insulation and atrium. Chapter 4 of Part III have codes on energy efficiency and site sustainability. Some of the codes here consider climate and environment. It Includes codes on building envelope and energy efficient building systems. In summary these building codes are not exclusively declared as climate-sensitive building codes but are indeed mentioned in BNBC [4] to address climate and environment.

2.2.1.2 Climate-Sensitive Building Codes in BNBC 2020, Volume III, Part VIII

BNBC [5], Chapter 1 of Part VIII comprise of codes for electrical and electronic engineering services for buildings. Some of these codes address climate and environment through codes for lighting and illumination and lightning Protection of Buildings. Chapter 2 of Part VIII have codes for air-conditioning, heating and ventilation. Some of these codes are also associated with climate and the environment which includes codes on planning (orientation, building design and use of materials, ventilation), ventilation systems and energy conservation. Chapter 4 of Part VIII have codes for lifts, escalators and moving walks. The codes address climate and environment through codes for energy conservation. Chapter 5 of Part VIII have codes for water supply. The codes address climate and environment through codes for water sources and quality. Chapter 7 of Part VIII have codes for rainwater management. The codes address climate and environment through codes for rainwater harvesting. In summary these building codes are not exclusively declared as climate-sensitive building codes, but the building codes mentioned in BNBC [5] have an impact on the environmental elements and resources.

2.2.2 Climate-sensitive building codes and guidelines by United Nations Environment Programme

UNEP [31] states that inadequate quality data, no awareness of energy efficiency, and insignificant building code expertise or enforcement make it challenging for developing and implementing building codes in developing nations. UNEP [31] also mentions that the building codes have inadequate climate adaptation regulations in developing countries. Furthermore UNEP [31] states that to develop resilient building codes they need to be well-designed and consider future climate changes, enable builders, architects, and product suppliers to learn through dissemination, and need to enforce codes thorough inspections of the buildings.

In general approaches and design principles UNEP [31] opines the significance of building codes, political will and capacity, and the role of institutional policy frameworks in adapting the built environment, it provides design and construction principles which includes human-climate-building interactions, owner-driven reconstruction for adaptation, planning for damage and triage design for rapid reconstruction after disasters, and nature-based adaptation for design and construction. UNEP [31] also mentions adaptation ideas for thermal regulation and comfort; it encompasses building site and orientation, building configuration and layout, natural ventilation, shading and cooling surfaces, thermal adaptations, and materials for thermal comfort. UNEP [31] also proposes adaptation ideas for specific climate risks: flooding, droughts, and cyclones; it comprises design opportunities for changing rainfall patterns and droughts, adapting to stronger storms and flooding and adapting to cyclones and windstorms through roof, wall, building shape design, and material selection. Refer to Table 2, it is a summary of building codes from 2.2.1, 2.2.1.1, 2.2.1.2 and, 2.2.2.

Table 2
Comparative, climate, and environment related, code analysis

Codes and Standards	BNBC 2020, Volume I, Part III	BNBC 2020, Volume III, Part VIII	UNEP (2021)
Chapter 1	**General Building Requirements**	**Electrical and Electronic Engineering Services for Buildings**	**N/A**
	-Land Use Classification, -Requirements of Plots, -Open Spaces within a Plot, -Community Open Space and Amenities, -Landscaping, -Damp-Proofing and Waterproofing, -Ventilation, -Lighting and Sanitation, -Thermal Insulation, -Lightning Protection of Buildings, -Rat Proofing and Termite Proofing of Buildings, -Requirements for Buildings in Flood Prone and Coastal Regions of Bangladesh and -Requirements for Buildings in Other Disaster-Prone Areas.	-Lighting and Illumination and -Lightning Protection of Buildings	
Chapter 2	**N/A**	**Air-Conditioning, Heating and Ventilation**	**N/A**
		-Planning (Orientation, Building Design and use of Materials, Ventilation), -Ventilation Systems and -Energy Conservation	

Chapter 3	**Classification of Building Construction Types Based on Fire Resistance**	**N/A**	**General Approaches and Design Principles**
	-Weather Protection, -Projections (sunshades, cornices, projected balconies, and overhanging), -Insulation and -Atrium.		-Building codes, -Political will and capacity and -The role of institutional policy frameworks in adapting the built environment -It provides design and construction principles * Human-climate-building interactions, *Owner-driven reconstruction for adaptation, *Planning for damage and *Triage design for rapid reconstruction after disasters, -Nature-based adaptation for design and construction
Chapter 4	**Energy Efficiency and Site Sustainability**	**Lifts, Escalators and Moving Walks**	**Adaptation ideas for Thermal Regulation and Comfort**
	-Building Envelope and -Energy Efficient Building Systems.	-Energy Conservation	-Building site and orientation, -Building configuration and layout, -Natural ventilation, -Shading and cool surfaces, -Thermal adaptations, and -Materials for thermal comfort
Chapter 5	**N/A**	**Water Supply**	Adaptation ideas for specific climate risks: flooding, droughts and cyclones
		-Water Sources and Quality	-It comprises design opportunities for changing rainfall patters and droughts, -Adapting to stronger storms and flooding, -Adapting to cyclones and wind-storms through roof, wall, building shape design -Material selection.
Chapter 6	**N/A**	**N/A**	**N/A**
Chapter 7	**N/A**	**Rainwater Management**	**N/A**
		-Rainwater Harvesting.	

Source: adapted from BNBC 2020 and UNEP 2021 guide by authors 2024

2.3 Climate-Sensitive Spatial Elements and Urban Density Reduction

Some spatial elements that address climate, such as setback, floor area ratio, open spaces, open spaces within a plot, community open spaces, courtyards, terraces, verandas, atriums, etc also reduce density, perceptual urban density and consequently encourage sustainable urban growth.

2.3.1 Courtyard in Traditional Urban Buildings

Shaida and Wezha [28] stated that environmental factors were extremely relevant to all the courtyard-housing forms through time. Rapoport [26], stated that there are five attributes of courtyard housing which are, privacy mechanism of courtyards, courtyard as either a system or a subsystem of a primary setting within which specific activities occur as part of dwelling itself, courtyard as a central space and circulation or transitional space, courtyard's efficiency and flexibility, and climatic efficiency and regulation.

In Bangladesh courtyard houses were adapted by traditional urban buildings from vernacular dwellings. Such courtyard houses are almost absent in modern urban buildings. These traditional, interactive and climate-sensitive spaces, such as courtyards, can be evolved through design to be accommodated in contemporary urban form to reduce urban density and address climate.

2.4 Significance of Courtyard as a Climate-Sensitive Building Code

According to Hatipoglu and Mohammad [22] it is crucial to continue certain architectural codes, by adapting these codes to the emerging dynamics, to cater to user needs and achieve a sustainable community. Hatipoglu and Mohammad [22] mentions that such dynamics include increased urban density and modified urban lifestyle; hence the courtyard house need to adapt to the contemporary scenario. Hatipoglu and Mohammad [22] states that since Syrian courtyard house have social and physical meaning it can be a modern urban development feature. Hatipoglu and Mohammad [22] mentions that the courtyard typology is ignored in modern urban setting, even though it provides good living environment, hence current housing development should be rethought about. According to Alic and Jadric, [1] courtyard housing in Vienna is now internationally renowned for social integration, demonstrating that such building typologies are necessary for integration and to create sustainable cities. Hatipoglu and Mohammad [22] states that it is a consequence of consistency in architectural codes and morphologies with the objective for social cohesion.

2.4.1 Courtyards in BNBC 2020

According to BNBC [4] courtyard should have maximum height (m) (height of the highest wall/ building enveloping the courtyard) and minimum net area of the interior courtyard (m2) according to its number of storeys (1 to 20) as mentioned in the code in section 1.8.10-Courtyard and Interior Courtyard; refer to Table 3. If the building is more than 20 storeys high the size of the interior courtyard should not be less than square of one-third the height of the tallest wall of the courtyard. The code also states that it should be open to sky from the formation level and should be surrounded by a building, group of building, walls, or combination of all. The shorter side of the courtyard should not be less than one-third of the longer side. If the sum of exposure through its walls exceeds more than thirty percent of the courtyard's peripheral enclosure, it will be called open courtyard. If the courtyard does not have this exposure, it will be called interior or closed courtyard. Only landscaping, sculptures, walkways, and waterbodies can be at the courtyard level and it should remain uninterrupted from other type of construction.

Table 3
Minimum Area of Interior Courtyard

No. of Stories	Maximum Height (m)	Minimum Net Area of the Interior Courtyard, m2
Up to 3	11	9
4	14	16
5	17	25
6	20	36
7	23	49
8	26	64
9	29	81
10	32	100
11	36	121

12-13	42	144
14-15	48	196
16-17	54	256
18-20	63	361

Source: BNBC 2020

2.4.2 Attributes of Courtyard that Reduce Urban Density and Addresses Climate

The courtyard provides the urban form encompassing it with heat, light, ventilation, and other functions. Bensalem [6] states that the size and shape of a courtyard play crucial role in addressing climate and ensures energy-conscious design. Ho [16] opines that courtyards are climate modifiers providing thermal comfort and it also provides spatial aspects in otherwise repetitive deep plans. Kim [21] states that the range of courtyard types and housing orientation affect density value. This research will be conducted with the courtyard building typologies referred in Figure 1 and 2.

Centralised Courtyard Semi-enclosed (L-shape) Semi-enclosed (U-shape)

Fig 1. South Facing Courtyard Typologies by authors 2024

Centralised Courtyard Semi-enclosed (L-shape) Semi-enclosed (U-shape)

Fig 2. North Facing Courtyard Typologies by authors 2024

3.0 Research Methodology

The research methodology adapted a mixed method approach, employing both quantitative and qualitative research methods for data collection, refer to Flow Chart 1.

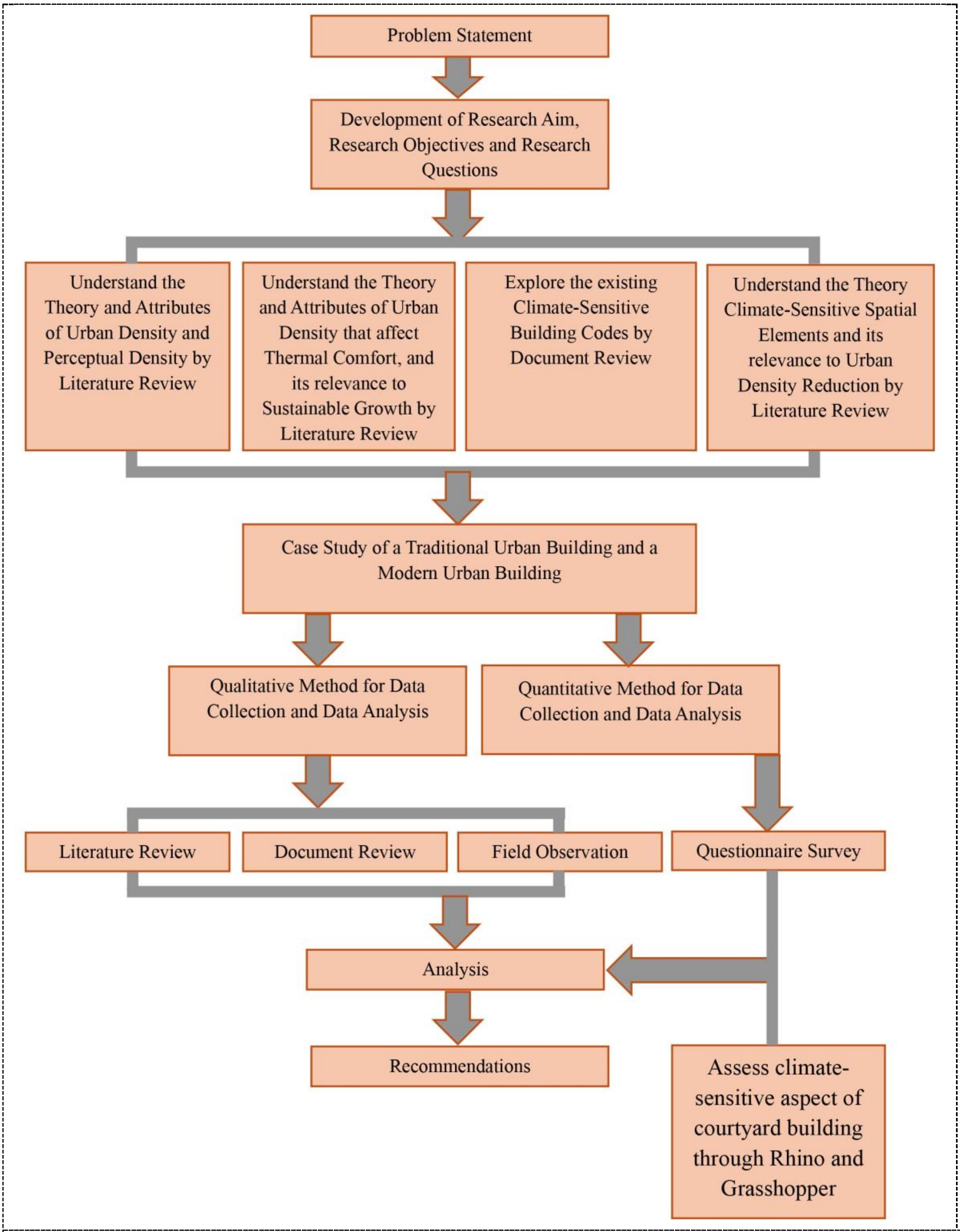
Firstly, climate-sensitive attributes that contribute to reducing urban density and encouraging sustainable growth were identified through literature review and evaluated by field observation. The case studies selected, for qualitative research, are a multistoried traditional urban residence in the heritage urban context of Panam City designed with climate-sensitive elements and a modern multistoried urban residential apartment in Dhaka which was designed maintaining building codes and acts. The findings were tabulated to distinguish the climate-sensitive elements in traditional urban buildings that can be incorporated in modern urban buildings to also reduce its urban density and encourage sustainable urban growth.

Secondly, the quantitative method included measuring the climate-sensitive aspect of courtyards through Rhino and Grasshopper and assessing the perceptual density, in a similar method as Beatrix [8], of a proposed street with modern courtyard buildings through questionnaires.

To assess the climate-sensitive characteristics of the building code on Courtyard and Interior Courtyard, in BNBC [4], section 1.8.10, two software were used to do simulation on the three-dimensional Rhino model of the modern multistoried residential apartment in Dhaka chosen as case study during field observation. The setback, maximum ground coverage and floor area ratio for the building was maintained as per building codes and acts, but a courtyard was incorporated in the three-dimensional Rhino model. The annual solar hour exposure of this three-dimensional Rhino building with courtyard at three different heights (three, five and eight stories) was simulated using Grasshopper with ladybug plugin.

To assess the perceptual urban density of a street at ground level, two three-dimensional Rhino model of the street was created; one three-dimensional Rhino model had modern buildings (prototypes of the modern multistoried residential apartment in Dhaka chosen as case study) with courtyards on both side of the street and the other three-dimensional Rhino model had usual buildings (prototypes of the modern multistoried residential apartment in Dhaka chosen as case study) with no courtyards on both side of the street. The setback, maximum ground coverage and floor area ratio was maintained as per building codes and acts in both cases. The two three-dimensional Rhino models were showed to people to record how people perceived the urban density for each of the cases.

Key findings indicated that many climate-sensitive features from traditional urban dwellings can be incorporated into new climate-sensitive building codes to reduce urban density. Finally, the study proposed possible climate-sensitive building codes aimed at reducing urban density and encouraging sustainable urban growth.



Flow Chart 1 Flow Chart of Research Methodology

4. Findings and Analysis

This section presents the analysis and recommendations based on the research questions, aim and objectives. The appraisal of climate-sensitive building codes to reduce urban density includes evaluation of climate-sensitive elements in traditional urban buildings that can be incorporated in modern urban buildings to reduce urban density, evaluation of building codes on courtyards to illustrate that it is a climate-sensitive building code, and evaluation of perceptual urban density through questionnaire survey to analyze how people perceive urban density when courtyards are introduced in modern urban buildings.

4.1 Evaluation of Climate-Sensitive elements in traditional buildings to Reduce Urban Density

A multistoried traditional urban residence in the heritage urban context of Panam City designed with climate-sensitive elements, refer to Figure 3 and 4, is compared with a modern multistoried urban residential apartment in Dhaka which was designed maintaining building codes and acts, refer to Figure 5. The comparative analysis of the two buildings is shown in Table 4; it shows that the traditional urban building had climate-sensitive elements which are not exclusively mentioned in the contemporary local codes as climate-sensitive elements. For example, BNBC [4-5] mentions about courtyard but does exclusively describe its capabilities as a climate sensitive, social integration and density reduction tool.

Fig 3. Façade of Panam city's traditional urban building

Fig 4. courtyard in Panam city's traditional urban building

Fig 5. Modern urban building

Table 4
Climate-Sensitive Features of Traditional and Modern Urban Buildings of Bangladesh

Attribute that affects thermal comfort	Types of buildings in this research	Operational variables of facade	Passive indicators of buildings for interior thermal comfort	Climate-sensitive building features that reduce Urban density
Façade, building orientation, design layout, material, and open spaces	Traditional urban building	Material	Wood (humidity buffer)	
			Stone (faster heat loss)	
			Brick (higher diffusion coefficient)	
			Lime mortar	
		Colour	Light colours	
		Shading Devices	Shutters (placed outside)	
			Lattice screen	
			Arcades	
			Extended Roof	
			Window depressed within thick wall for shade	
			Shade over Window	
		Architectural Features	Window (size, location, north-south orientation, double glazing, lower solar heat gain coefficient (SHGC) of the glass)	
			Openings in courtyards	✓
			Courtyard (Open to sky)	✓
			Balcony attached with rooms of upper floors in some cases.	
			Terrace- Few per building but larger sizes.	✓
			Veranda- Few per building but larger sizes.	✓
			Buffer spaces (arcaded passage surround internal rooms)	✓
			Inclined Roof extension (with conical tiles/ clay tiles)	
			Cavity walls	
			Tall rooms	
	Modern urban building	Material	Brick	
			Concrete	
			Glass	
			Steel	
		Colour	Varied	
		Shading Devices	Inadequate	
		Architectural Features	Large windows	
			No Courtyards but rarely atrium is present but mostly covered with glass	
			Balcony with less depth	
			Terrace- More in number per building but smaller sizes.	

			Veranda- More in number per building but smaller sizes.	
			No buffer space from internal rooms except the attached veranda or terrace if present	
			Roofs are not always extended	
			Flat Roof	
			Wall 5" to 10" of residences with no cavity	
			The rooms are 9'-6" to 10'-0" high	

Source: Authors 2024

4.2 Evaluation of Codes on Courtyards to illustrate that it is a Climate-Sensitive Building Code

The simulation was done to assess the climate-sensitive characteristics of the building code on Courtyard and Interior Courtyard, in BNBC [4], section 1.8.10. Refer to Figure 5,6,7,8,9, and 10 for the simulation results. The courtyard dimension is adequate when the height is more but insufficient if it is a three storied building for all types of courtyards tested in this research refer to Figure 1 and 2. Even though the L shaped courtyard is getting good sunlight at all circumstances, the U-shaped courtyard is performing most efficiently among the courtyard typologies especially if its opening is directed at the south. Considering the area requirements for courtyard in the codes for every respective increase in height, the U-shaped courtyard is more effective at taller buildings. The centralized courtyard is more like a shaft because the area mentioned as per its height in the code is inadequate. Hence it can be concluded that this evaluation did prove the courtyard to be a climate-sensitive tool for thermal comfort, but the given code can be further modified to enable the courtyard to address the climate more efficiently.

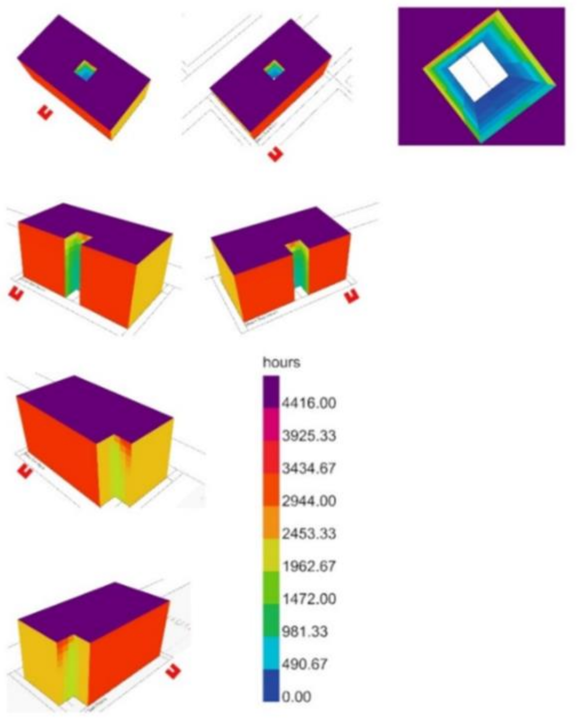


Fig 5. South facing courtyard (central, U and L shape) in a three storied modern building.

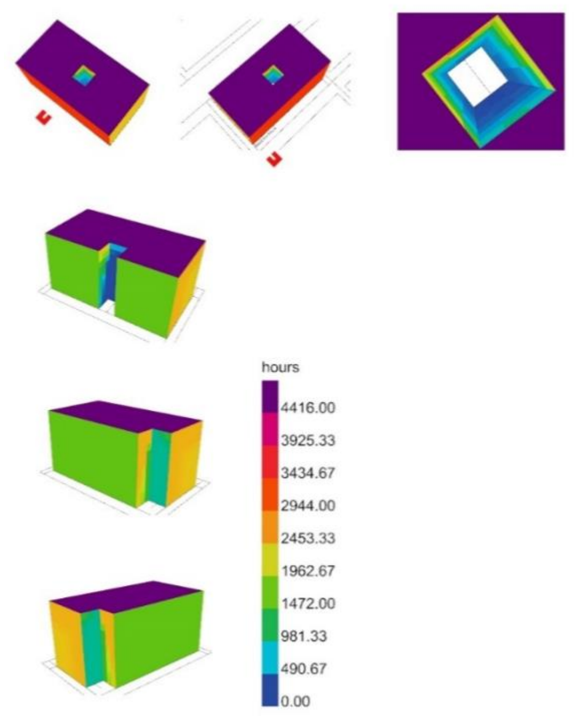


Fig 6. North facing courtyard (central, U and L shape) in a three storied modern building.

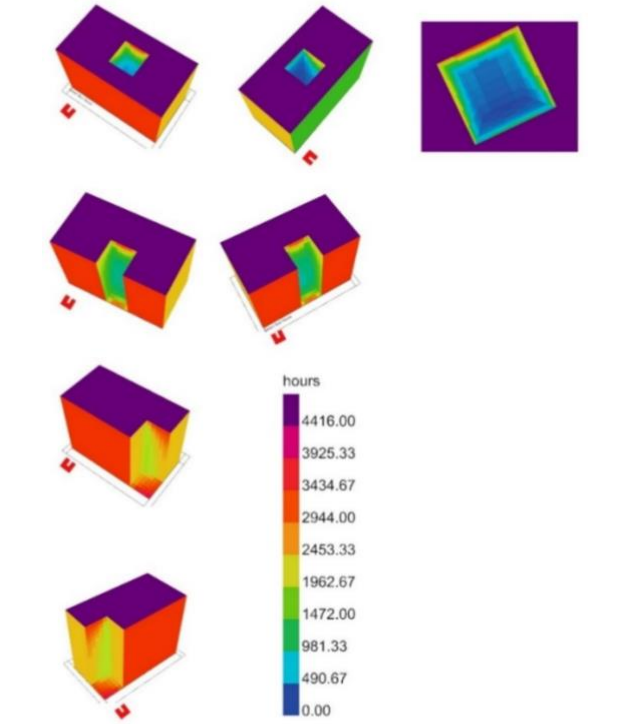


Fig 7. South facing courtyard (central, U and L shape) in a Five storied modern building.

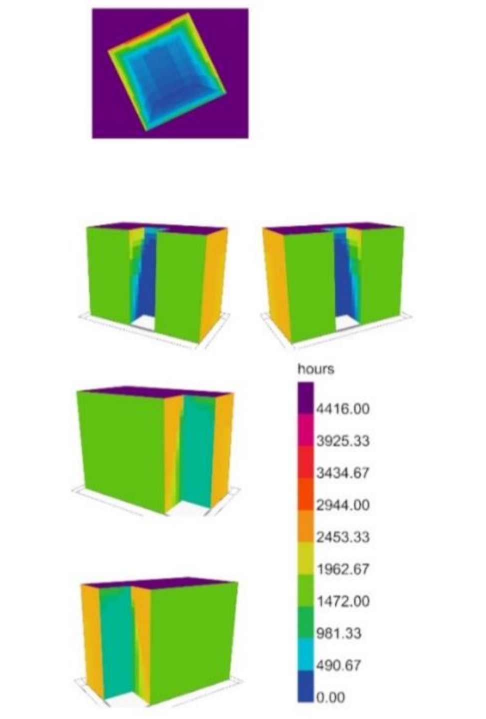


Fig 8. North facing courtyard (central, U and L shape) in a Five storied modern building.

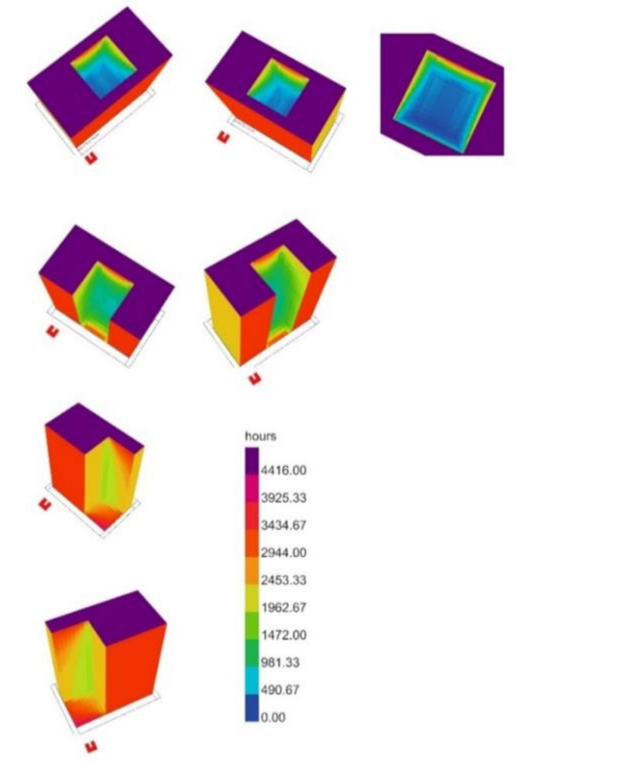


Fig 9. South facing courtyard (central, U and L shape) in a Eight storied modern building.

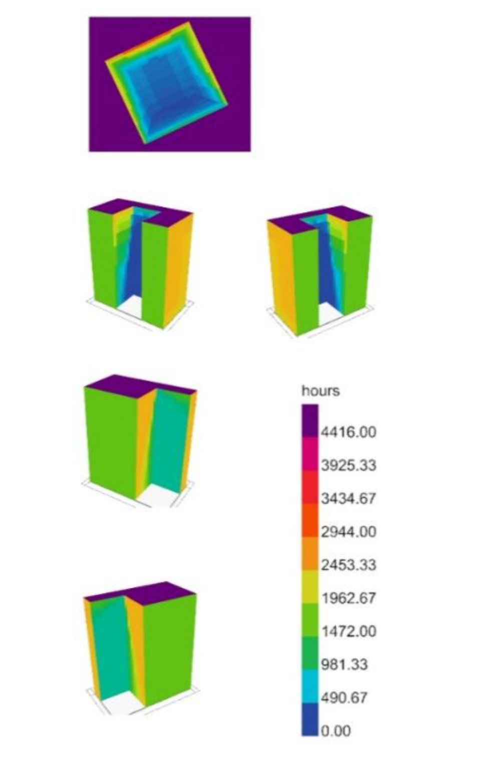


Fig 10. North facing courtyard (central, U and L shape) in a Eight storied modern building.

4.3 Evaluation of perceptual urban density through Questionnaire Survey

A questionnaire survey was conducted with 100 random participants. Fig 11 and 12 was shown to record their response about the perceptual density created by the two images. It was seen that the image with courtyard buildings was chosen to be less dense by majority.

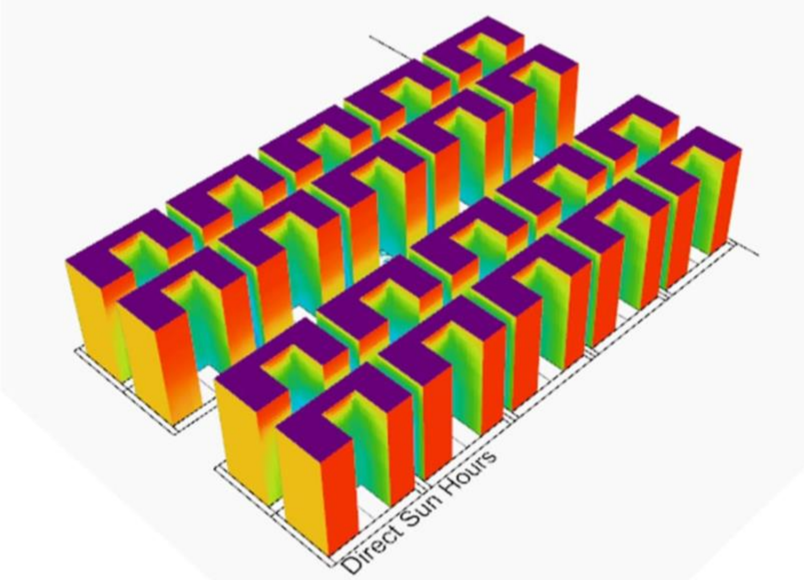


Fig 11. Street with South facing U shaped courtyard buildings

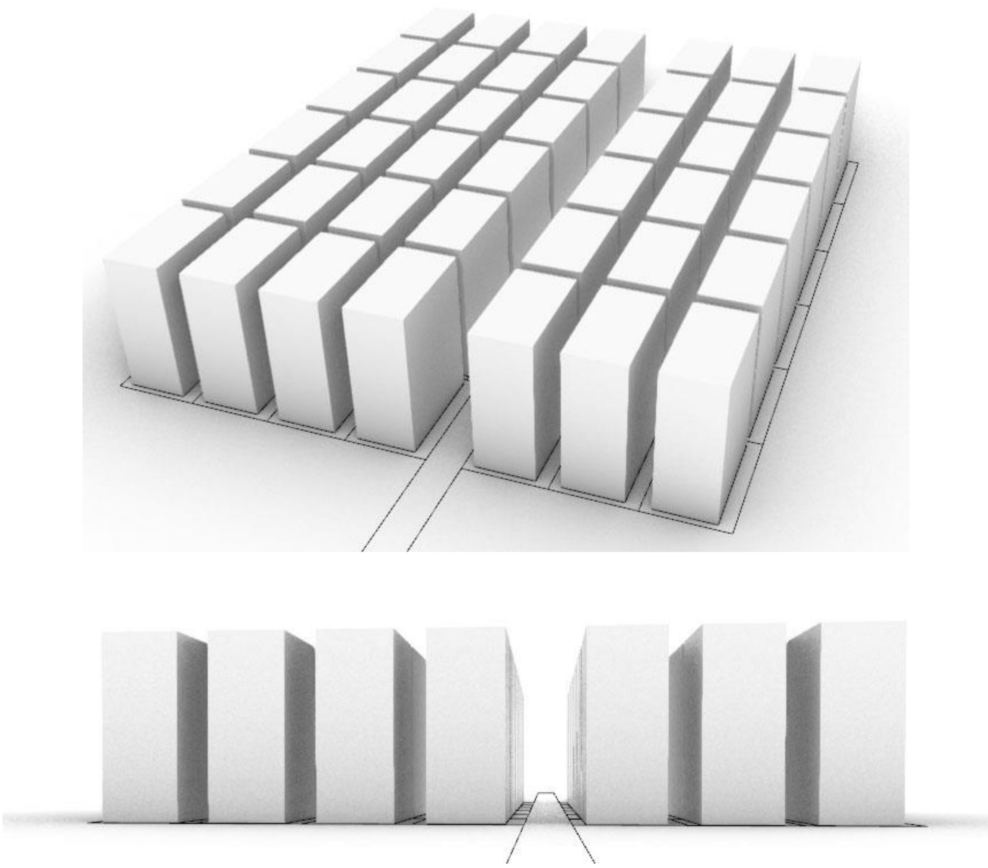


Fig 12. Typical street in Dhaka with no courtyard buildings

5.0 Limitation, Recommendation and Conclusion

This research only considered the courtyard as a climate-sensitive spatial element to reduce urban density and assessed climate-sensitivity of the local building codes, for the courtyard, only through thermal comfort aspect. Hence this research focused on how the courtyard, as a climate-sensitive spatial element, reduces perceptual urban density and encourages thermal comfort leading to sustainable urban growth.

In the context of Dhaka city climate-sensitive building codes are necessary to address climate for thermal comfort, reduce energy consumption and reduce urban density to ensure sustainable urban growth. This research has established that even though BNBC [4-5] has extensive codes there is still room to modify it and reestablish many of these codes exclusively as climate-sensitive codes. Some of these climate-sensitive codes such as the codes on courtyard, setback, FAR, and open spaces can be promoted as codes which can also reduce urban density effectively.

It is recommended to install climate-sensitive attributes of traditional urban building in modern urban buildings, by implementing through codes and acts, to address climate efficiently and reduce urban density. This research advocates that in a dense urban context like Dhaka courtyard buildings throughout the street can be introduced, by implementing through building codes and acts, to reduce perceptual urban density. It is also advised that the courtyard buildings should have a U shape courtyard facing the south for better thermal comfort. In BNBC [4], section 1.8.10, the building code on Courtyard and Interior Courtyard for three storied building should be modified to increase thermal comfort. Also, the centralised courtyard type acts like a shaft as per the guidelines of BNBC [4] and needs necessary modification to function like a courtyard. Moreover, the urban forms can be modified with climate-sensitive spatial features such as terraces, veranda and courtyard to reduce both urban density and perceptual urban density. Furthermore, parks and playgrounds should be encouraged as it acts as climate-sensitive elements and reduces density.

Extensive research is still necessary, in all attributes of density to propose more holistic climate-sensitive building codes to reduce urban density and encourage sustainable urban growth.

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