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Effect of Orientation and Window Wall Ratio in Residential Buildings Within Town Planning – A Case of Ratodada Town Planning, Lamahi, Dang

by

Subash Kalathoki

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DECLARATION

I hereby declare that the thesis entitled **"Effect of Orientation and Window Wall Ratio In Residential Buildings Within Town Planning – A Case of Ratodada Town Planning, Lamahi, Dang"** submitted to the Department of Architecture in partial fulfilment of the requirement for the degree of Master of Science in Energy Efficient Buildings, is a record of an original work done under the guidance of Associate Prof. Dr. Sanjaya Uprety and Ar. Barsha Shrestha, Institute of Engineering, Pulchowk Campus. This thesis contains only work completed by me except for the consulted material which has been duly referenced and acknowledged.

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ABSTRACT

This thesis explores energy efficiency considerations in residential areas, focusing on the optimization of building orientation and window-to-wall ratios (WWR) for enhanced energy performance in the Lamahi land pooling area. The research aims to identify key strategies that balance energy consumption, thermal comfort, and daylight availability, emphasizing the relevance of building design in temperate climates.

Through data collection and simulation techniques, the study investigates various building orientations (0°–180°) and WWRs (10%–60%) to determine their effect on energy consumption and daylight penetration. Two optimized models emerged from the simulations: Optimized Model 1, featuring a WWR of 50% with no change in orientation (0°), and Optimized Model 2, with a WWR of 40% and a 30° change in orientation. Both models demonstrated significant improvements in energy use and daylight efficiency, whereas WWRs below 40% and above 50%, as well as orientations of 60° or 90°, were found to cause inefficiencies.

The findings underline the critical importance of balancing WWR and building orientation to optimize energy efficiency, ensuring both thermal comfort and natural lighting. The research further contributes to understanding the specific energy challenges of residential areas within land pooling projects, offering actionable insights for sustainable urban planning and building design in temperate climates, with a focus on the Lamahi case study area.

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ABBREVIATION AND ACRONYMS

HVAC	Heating, Ventilation, and Air Conditioning
LEED	Leadership in Energy and Environmental Design
BMS	Building Management System
EPC	Energy Performance Certificate
GHG	Greenhouse Gas
PV	Photovoltaic
LED	Light Emitting Diode
BREEAM	Building Research Establishment Environmental Assessment Method
FSD	Full Spectrum Daylight
ECBC	Energy Conservation Building Code
R-value	Thermal Resistance Value
U-value	Heat Transfer Coefficient
O&M	Operations and Maintenance
RCP	Representative Concentration Pathway
BIM	Building Information Modeling

CHAPTER 1: INTRODUCTION

1.1 Background and Context

Energy efficiency in residential buildings is crucial in reducing energy consumption and lowering environmental impacts. Buildings account for approximately 30–40% of global energy use, and improving their performance can result in substantial reductions in energy demand and greenhouse gas emissions (Yang et al., 2015; IEA, 2021). Enhancing energy efficiency not only contributes to environmental sustainability but also promotes economic savings for homeowners by reducing utility costs. Key architectural design strategies, such as optimizing the window-to-wall ratio (WWR), building orientation, insulation, and material selection, play vital roles in minimizing heating and cooling demands and thus enhancing the energy performance of residential buildings (Heidari et al., 2019).

Optimizing design elements like WWR has proven to be particularly impactful. Studies indicate that a WWR of 20% to 35% is generally optimal for balancing daylight availability and thermal performance, enhancing indoor comfort while minimizing heat gain or loss (Alwetaishi & Benjeddou, 2021). Additionally, the use of high-performance glazing materials in windows can further reduce unwanted heat transfer and improve insulation properties, thereby improving the overall thermal efficiency of a building (Attia et al., 2012). In various climatic regions, including temperate and tropical zones, building orientation is equally significant. For instance, south-facing orientations in the Northern Hemisphere allow for maximum solar gain during winter and minimal overheating in summer when properly shaded, leading to reduced reliance on mechanical heating and cooling systems (Uprety et al., 2021).

In the context of Nepal, empirical research on residential buildings in cities like Butwal and Kathmandu has shown that incorporating passive design strategies such as optimal orientation and appropriate WWR can lead to significant reductions in energy consumption for lighting, cooling, and heating (Uprety et al., 2021). Moreover, daylighting strategies integrated with effective architectural planning—such as the placement of skylights, light shelves, and clerestory windows—enhance natural illumination and decrease dependency on artificial lighting during daytime, contributing further to energy conservation (Sangraula & Uprety, 2020). Ventilation strategies, including cross ventilation and stack ventilation, also complement energy-

efficient designs by improving indoor air quality and reducing the need for energy-intensive mechanical ventilation systems (Nguyen & Aiello, 2013). Collectively, these strategies offer a comprehensive approach to improving energy efficiency in residential buildings while ensuring occupant comfort and environmental responsibility.

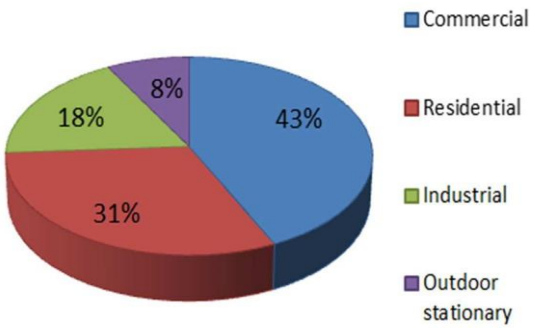

Figure 1 Global energy consumption by sectors (IEA, 2023)

Urban developments, particularly in rapidly growing areas, exhibit distinct energy consumption patterns driven by increasing housing demands, densification, and the accelerated pace of construction. In cities like Kathmandu, where rapid urbanization often outpaces strategic urban planning, residential buildings are frequently constructed with limited regard for energy efficiency principles. As a result, these structures tend to exhibit high energy use stemming from suboptimal design choices, such as excessive window-to-wall ratios (WWR), inappropriate orientation, and inadequate insulation (Shrestha & Uprety, 2023). These issues are further compounded by the adoption of construction practices that prioritize short-term economic gains over long-term energy performance. The lack of regulatory enforcement and public awareness regarding passive design strategies also contributes to inefficient building stock in urban Nepal.

Research conducted in China's hot summer and cold winter climatic zones has demonstrated that WWR has a direct and substantial impact on building energy consumption. Larger window areas typically increase cooling loads in summer due to greater solar heat gain and raise heating demands in winter due to thermal losses, indicating the need for climate-responsive façade design (Yang et al., 2015). Similarly, findings from urban studies in Iran and Afghanistan emphasize the significance of integrating passive design elements such as shading devices, thermal mass, and orientation-specific window placement to reduce dependence on mechanical heating and cooling systems (Karimi et al., 2023). In many Middle Eastern and South Asian

cities experiencing rapid urbanization, these design strategies have shown potential in reducing annual energy consumption while enhancing thermal comfort and indoor air quality.

The role of computational tools in achieving optimal building performance has become increasingly vital in the context of sustainable urban development. These tools allow architects, planners, and engineers to simulate and analyze various design configurations, making it possible to predict and enhance energy efficiency before physical construction begins. Dynamic building performance simulations, such as EnergyPlus, DesignBuilder, and Autodesk Insight, are widely used in parametric studies to identify optimal WWRs and orientation strategies tailored to specific climatic conditions (Bagheri et al., 2024). For instance, a study in Rasht, Iran, revealed that a south-facing WWR of 21–25% achieved the lowest annual energy consumption, balancing natural daylight with thermal regulation (Bagheri et al., 2024).

In addition to optimizing WWR, these computational models evaluate factors like glazing type, shading elements, insulation thickness, and occupancy patterns to provide a comprehensive understanding of building energy behavior. Research in Saudi Arabia and China further illustrates how façade modifications assessed through simulation software can accurately predict heating and cooling loads, supporting evidence-based design decisions (Alwetaishi & Benjeddou, 2021; Yang et al., 2015). Moreover, in Nepal, the implementation of such tools in urban planning and residential design has shown promising outcomes. A study conducted in Kathmandu using dynamic modeling identified optimal design parameters, including WWR, that maximize daylight penetration while minimizing cooling and lighting energy demands (Basnet & Uprety, 2022). These findings underscore the transformative potential of simulation-driven design in enhancing energy performance not only in new constructions but also in retrofitting existing buildings. As urban areas continue to expand, the adoption of these technologies is essential to achieving long-term sustainability goals and creating resilient, low-carbon urban environments.

1.2 Importance of the research

Energy efficiency in residential buildings is crucial for sustainable urban planning, especially in the context of rapidly growing cities where energy demand is rising due to urbanization and population growth. As cities expand and more residential areas are

developed, the energy consumed for lighting, heating, cooling, and ventilation increases significantly. Despite this, energy efficiency has not historically been a primary consideration in spatial planning or urban development strategies in Nepal (Nakarmi, Shah, & Uprety, 2020). Instead, urban growth has often been reactive and unregulated, resulting in building forms and orientations that are incompatible with passive design principles. This oversight contributes to increased operational energy consumption and a growing dependency on artificial lighting and mechanical systems for thermal comfort.

This research investigates the impact of optimizing window-to-wall ratio (WWR) and building orientation on residential energy use while maintaining indoor thermal comfort. These two design parameters—WWR and orientation—are critical in determining the extent of heat gain, daylight penetration, and ventilation potential within a building. Poorly designed buildings with excessive glazing on inappropriate façades often lead to overheating in summer and heat loss in winter, necessitating more energy for cooling and heating. Computational studies have shown that an optimized WWR, often between 20% and 35%, can significantly reduce thermal loads while maintaining acceptable daylighting levels (Alwetaishi & Benjeddou, 2021). Similarly, orienting buildings to align with solar trajectories enhances passive solar heating in colder seasons and minimizes heat gain in warmer periods, contributing to year-round energy savings (Heidari et al., 2019).

Inefficient urban planning that overlooks these design principles often leads to environments that are heavily reliant on energy-intensive systems. For instance, dense residential clusters with poor orientation block natural light and airflow, creating dark and poorly ventilated interiors that necessitate constant use of lighting and air-conditioning systems. This not only raises operational costs for residents but also places additional strain on national energy infrastructure, which in Nepal is already facing challenges in meeting peak electricity demands, particularly during dry seasons (Uprety & Basnet, 2021).

This study uses computational simulation tools such as EnergyPlus and DesignBuilder to generate data-driven insights into how different WWRs and orientations affect building energy performance. These tools allow for dynamic modeling of real-world scenarios, incorporating variables such as local climate data, occupancy patterns, glazing types, and thermal properties of materials. Simulation results support evidence-

based design recommendations that can directly inform zoning regulations, building codes, and urban planning policies. For example, studies have shown that applying simulation outputs in early-stage planning leads to a 20–30% reduction in annual energy consumption compared to traditionally designed homes (Pathirana et al., 2019).

The implications of these findings are far-reaching. By embedding energy efficiency into urban planning frameworks, municipalities can create residential environments that are not only environmentally sustainable but also socially equitable and economically beneficial. Improved building codes that mandate consideration of WWR and orientation can drive better design practices among architects and developers. Furthermore, policy support for simulation-based design processes can institutionalize sustainability in the construction industry. Ultimately, adopting such strategies contributes to a lower urban carbon footprint, enhances urban livability, and aligns with Nepal's national and international commitments to climate action and sustainable development.

1.3 Problem statement

Town planning often suffers from energy inefficiencies due to a lack of coordination and absence of energy-consciousness. In Nepal, studies have shown that residential buildings in planned areas, such as those in Kathmandu Valley, experience high energy demand due to poor building orientation, excessive window-to-wall ratios (WWR), and inadequate shading strategies (Shrestha & Uprety, 2023).

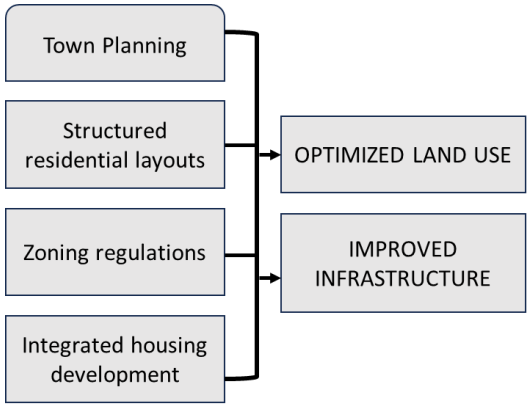

Figure 2 Urban development strategies and their aim

Figure 2 illustrates the interconnected elements of urban development strategies that contribute to optimized land use and improved infrastructure. On the left side, it highlights four key components: Town Planning, Structured Residential Layouts,

Zoning Regulations, and Integrated Housing Development. Each of these elements plays a critical role in guiding how land is utilized, ensuring that residential areas are developed in a well-organized, systematic manner. Town planning sets the overarching vision and framework for development, while structured residential layouts ensure that neighborhoods are designed with efficiency, accessibility, and comfort in mind. Zoning regulations support this by delineating land for specific purposes—residential, commercial, industrial, etc.—thereby reducing land-use conflicts and encouraging orderly growth. Integrated housing development brings together different types of housing and amenities in a cohesive manner, promoting inclusivity and reducing urban sprawl.

On the right side of the figure, the outcomes of these planning measures are summarized as Optimized Land Use and Improved Infrastructure. When applied effectively, these planning tools ensure that land is used to its maximum potential without overburdening natural resources or existing urban systems. This leads to better access to services such as water supply, transportation, electricity, and waste management, forming the backbone of improved infrastructure. The diagram emphasizes how strategic planning and regulatory mechanisms directly influence urban efficiency and livability, underlining the importance of proactive governance and multidisciplinary collaboration in urban development.

Research conducted in China's urban settlements indicates that improper WWR design can result in significant heating and cooling losses, increasing annual energy consumption by up to 30% (Yang et al., 2015). Similarly, studies from Saudi Arabia highlight that large, unshaded window in residential buildings contribute to higher cooling loads, leading to greater electricity consumption (Alwetaishi & Benjeddou, 2021). Additionally, Nepalese studies have pointed out that many residential buildings in these areas lack passive cooling techniques, such as cross-ventilation and strategic shading, further exacerbating energy demand (Chaulagain et al., 2021). These inefficiencies highlight the need for context-specific energy-efficient design interventions in urban planning.

1.4 Research Gap

A major challenge in residential building design is the lack of systematic consideration of key design parameters that significantly influence energy performance. Many

residential developments, particularly in developing countries, are executed without rigorous analysis of critical factors such as window-to-wall ratio (WWR), building orientation, glazing type, shading devices, thermal mass, and insulation (Shrestha & Raut, 2020). These elements, when properly optimized, can drastically reduce a building's dependence on mechanical heating, ventilation, and air conditioning (HVAC) systems. However, design decisions in many cases are based primarily on aesthetics, construction cost, or land constraints rather than on performance metrics. As a result, residential buildings often exhibit poor thermal performance, discomfort for occupants, and higher operational energy demand throughout their lifecycle.

Studies conducted in countries like Iran and Afghanistan emphasize the climate-specific optimization of WWR to achieve a balance between natural daylighting, effective cross-ventilation, and thermal comfort while simultaneously minimizing energy losses and overheating (Karimi et al., 2023; Heidari et al., 2019). For instance, arid climates require smaller WWRs with proper shading to avoid solar heat gain, while temperate or cold climates can benefit from larger south-facing windows to enhance passive solar heating. In Nepal, however, energy-sensitive design parameters are still largely absent from national building codes and urban housing guidelines. According to Sangraula and Uprety (2020), this regulatory gap has contributed to a proliferation of inefficient building practices, especially in rapidly urbanizing areas like the Kathmandu Valley.

Computational simulations using tools such as EnergyPlus, Rhino-Grasshopper, and DesignBuilder have demonstrated that even minor adjustments in window placement, glazing selection, and orientation can lead to significant reductions in both heating and cooling energy loads (Bagheri et al., 2024). For example, simulation-based research in tropical and subtropical climates has shown that optimizing WWR and orientation can lower cooling energy demand by up to 25% while maintaining visual and thermal comfort (Pathirana et al., 2019). These findings are particularly relevant to Nepal's diverse climatic zones, where microclimate-sensitive design could greatly enhance energy efficiency. Furthermore, empirical studies in Kathmandu and Pokhara have highlighted that performance-based approaches, such as dynamic thermal modeling, are still underutilized in local architectural practices (Basnet & Uprety, 2022).

Despite the proven benefits of performance-driven design, many residential projects continue to be planned and constructed using conventional methods, often with minimal

stakeholder engagement or environmental analysis. This perpetuates a cycle of high energy consumption, occupant discomfort, and increased greenhouse gas emissions over time. Addressing this gap requires not only the integration of energy-efficient design principles into building regulations but also capacity building among professionals, greater awareness among homeowners, and stronger enforcement mechanisms. Additionally, promoting the use of energy simulation tools in early design phases could empower architects and planners to make informed decisions that align with sustainability goals. Ultimately, bridging this gap is essential for advancing energy-efficient housing and supporting Nepal's broader commitments to climate resilience and sustainable urban development.

1.5 Research objective

The primary objective of this study is to evaluate the impact of building orientation and window-to-wall ratio (WWR) on the energy consumption of residential buildings in Ratodada Town Planning, Lamahi.

The specific objectives adopted for achieving primary objectives are:

- Evaluate the impact of varying WWR on daylight access, and energy consumption.
- Assess the effect of different orientations on daylight and energy consumption.
- Identify optimal orientation and WWR configurations to enhance energy efficiency in residential buildings.

1.6 Topic validity

The study of energy efficiency in urban planning is highly relevant due to the increasing energy demands in residential areas and the urgent need for sustainable and climate-responsive design solutions. In recent decades, rapid urbanization has intensified pressure on infrastructure, energy supply systems, and environmental resources, particularly in developing countries like Nepal. Within this context, the optimization of building design parameters—especially building orientation and window-to-wall ratio (WWR)—has emerged as a key strategy to mitigate energy consumption related to heating, cooling, and lighting. These two variables are fundamental in determining how buildings interact with their surrounding environment, influencing solar heat gain, natural daylight penetration, and ventilation (Heidari et al., 2019; Pathirana et al., 2019). Numerous studies across diverse climatic zones—from the hot-humid regions

of Southeast Asia to the cold-arid areas of the Middle East—have demonstrated that careful manipulation of WWR and orientation can result in energy savings of 20–40% depending on climate and design context (Karimi et al., 2023; Alwetaishi & Benjeddou, 2021).

Despite this global evidence, there remains a significant gap in localized, context-specific research for government-led urban initiatives, such as the Lamahi town planning project in Nepal. These projects often follow standardized development templates that overlook critical passive design principles, leading to long-term inefficiencies in building performance. This study addresses that gap by integrating field-based energy consumption surveys with dynamic computational simulations to assess how WWR and orientation affect energy loads in the Lamahi region. By calibrating simulation models with actual household energy data, the research provides both empirical evidence and predictive insights that can guide future design and policy decisions. This dual approach ensures that the findings are not only theoretically grounded but also practically applicable.

The results from this study are expected to inform municipal authorities, planners, and architects involved in the development of residential zones within government-planned towns. They will also support the formulation of updated building codes and urban planning guidelines that prioritize energy efficiency without compromising affordability or structural safety. Furthermore, given Nepal's growing urban footprint and rising residential electricity demand, especially in newly developed peri-urban areas, this research contributes to broader national objectives related to climate change mitigation and sustainable development. It aligns with global sustainability frameworks such as the United Nations' Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 7 (Affordable and Clean Energy). Ultimately, this study offers a replicable methodology and a data-driven foundation for promoting energy-conscious residential planning in other emerging towns across Nepal and the Global South.

1.7 Conceptual framework

The conceptual framework for this study is designed to explore the impact of two key building design parameters - WWR and building orientation on energy consumption in planned urban areas. These two independent variables are central to understanding the

energy performance of the residential buildings. WWR influences the amount of natural light entering a building and determines the extent of heat gain or loss, while building orientation affects the exposure of windows to sunlight, thus impacting solar heat gain and the need for cooling or heating.

The dependent variable in this framework is energy consumption, specifically the demand for heating, cooling, and lighting. By using both an energy consumption survey and computational simulations, the study aims to assess how variations in WWR and orientation affect overall energy use. These tools allow for a more precise evaluation of energy loads under different design configurations, ultimately leading to optimized, energy-efficient urban planning strategies.

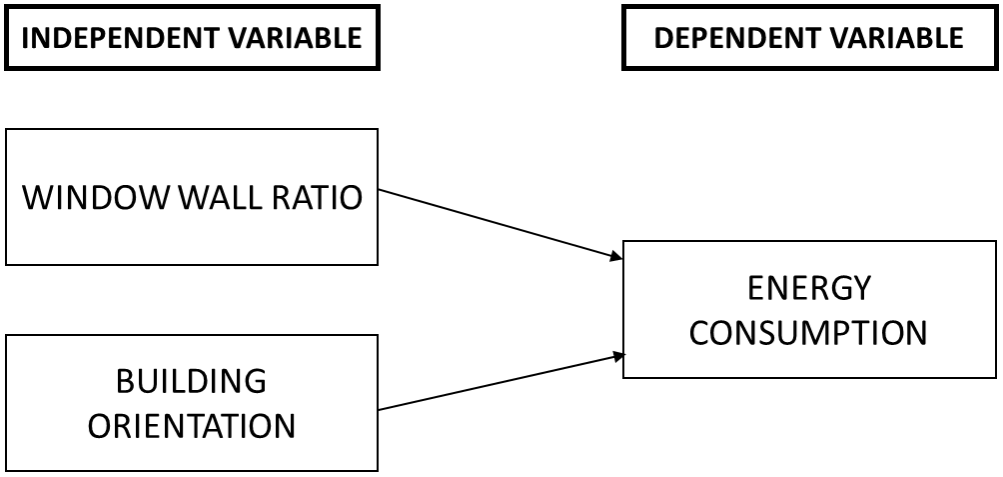

Figure 3 Conceptual framework of the research

The figure presents a conceptual framework for achieving energy-efficient urban residential planning by integrating key architectural design parameters, analytical tools, and policy development. On the left, it highlights critical design elements such as window-to-wall ratio (WWR), building orientation, glazing type, and thermal mass. These parameters significantly influence a building's energy performance by affecting factors like solar heat gain, natural daylight, ventilation, and thermal comfort. Proper optimization of these elements is essential for minimizing reliance on artificial heating, cooling, and lighting systems, ultimately contributing to lower energy consumption.

At the center of the framework are analytical tools, including energy consumption surveys and computational simulations, which are used to assess the impact of various design scenarios on energy use. These tools allow architects and urban planners to evaluate the energy performance of buildings before construction, using data-driven

insights to determine the most efficient configurations. On the right side, the framework shows how the results from these analytical processes inform urban planning policies and building code development. By embedding energy-efficient design principles into regulatory standards and planning strategies, the framework ensures that sustainability is not just an architectural choice but a planning mandate. This integrated approach is particularly relevant in the context of planned developments like Lamahi town in Nepal, where there is a unique opportunity to incorporate passive design strategies and energy simulations into the foundational planning process for long-term environmental and economic benefits.

1.8 Scope and limitation

1.8.1 Scope

The scope of this thesis encompasses the integration of passive design strategies and energy efficiency principles into residential urban planning, with a specific focus on government-initiated town developments such as Lamahi in Nepal. As urbanization accelerates, residential energy demand continues to rise, placing pressure on national energy resources and increasing environmental impact. Despite this trend, spatial and town planning in Nepal has historically overlooked energy as a key design criterion (Nakarmi, Shah, & Uprety, 2020). This research addresses that gap by evaluating the influence of critical architectural parameters—specifically Window-to-Wall Ratio (WWR) and building orientation—on the energy performance of residential buildings. The scope extends to understanding how these factors interact with local climatic conditions to affect heating, cooling, and lighting loads in urban dwellings.

Another key component of this thesis is the application of energy consumption surveys and computational simulation tools to generate data-driven insights. These tools allow for a comprehensive assessment of how variations in WWR, orientation, and other passive elements impact overall energy efficiency and indoor thermal comfort. By analyzing both empirical data and simulated models, this study provides a dual approach to understanding and optimizing energy performance in planned residential areas. The findings are intended not only to support the development of more efficient building designs but also to inform urban policy and planning guidelines that promote sustainability at a broader scale.

The thesis also explores the potential for integrating these design and analytical

approaches into Nepal's regulatory and planning frameworks. It considers how energy modeling can support the formulation of building codes and zoning regulations that prioritize energy efficiency in urban expansion projects. By focusing on a real-world case like Lamahi town planning, the study situates its findings in a practical and replicable context, ensuring the relevance of its recommendations for other emerging urban areas in Nepal and similar developing regions. Ultimately, this thesis aims to contribute to the creation of energy-conscious, sustainable, and livable urban environments aligned with national goals and global sustainability targets.

1.8.2 Limitations

The study has several limitations that could impact the breadth and applicability of its findings. Firstly, the geographic scope is limited to a single town development (Lamahi), which may restrict the generalizability of the results to other regions with different climatic, social, or urban contexts. Additionally, access to reliable and comprehensive data on household energy consumption is a challenge, as inconsistencies or limitations in the data can affect the accuracy of survey-based analyses. Furthermore, while computational simulations were used, they were simplified models that might not capture all real-life complexities, such as variations in user behavior, appliance efficiency, or construction material differences that can significantly influence energy consumption. The study also excludes socioeconomic factors, focusing mainly on architectural and environmental parameters, which means it may not account for how factors like economic status, household size, or lifestyle choices affect energy use. Even if optimal design strategies are identified, policy implementation may be hindered by gaps in enforcement, a lack of awareness, or outdated regulatory frameworks. Technological constraints, such as limited access to advanced simulation software, insufficient hardware capacity, or a lack of technical expertise, could also impact the quality of the results. Moreover, time and resource constraints could restrict the depth of field surveys, simulations, and data analysis, as these processes are time-consuming and dependent on available resources. Additionally, no simulations were conducted on shading devices for houses, and only box modeling was used for simulation purposes, which limits the accuracy of the results in reflecting real-world shading effects on energy use.

CHAPTER 2: LITERATURE REVIEW

2.1 Energy efficiency in residential buildings

Energy efficiency in residential buildings plays a crucial role in sustainable development, addressing both environmental concerns and economic benefits. Globally, buildings account for a significant share of energy consumption and carbon emissions, prompting countries to adopt stringent policies and innovative design strategies to reduce energy demand while maintaining occupant comfort. According to the International Energy Agency (IEA, 2019), the building sector is responsible for 36% of global energy use and nearly 39% of energy-related carbon dioxide emissions. This has led to the development of international standards such as the Passive House Standard in Germany and the Leadership in Energy and Environmental Design (LEED) certification in the United States.

Energy-efficient buildings are designed to reduce energy consumption while maintaining occupant comfort(Rossi & Visoli, 1995). These buildings integrate various strategies that focus on minimizing heating, cooling, and lighting demands. Key factors influencing energy efficiency include the building's orientation, window-to-wall ratio (WWR), insulation, and use of sustainable materials(Abanda & Byers, 2016). An optimal WWR, for example, ensures a balance between daylighting and thermal performance, helping to reduce energy consumption for lighting and temperature control (Heidari et al., 2019). Building orientation plays a crucial role in maximizing passive solar heating and minimizing heat loss or gain, thus reducing the reliance on mechanical systems (Alwetaishi & Benjeddou, 2021). Additionally, incorporating renewable energy sources, such as solar panels or wind turbines, and adopting energy-efficient technologies like LED lighting and high-performance HVAC systems, further contribute to reducing energy demand (Yang et al., 2015). Energy-efficient buildings not only lower operational costs but also reduce the environmental impact, contributing to the overall sustainability of urban development (Sangraula & Uprety, 2020). Numerous studies have shown that implementing energy-efficient design strategies can lead to significant reductions in energy use and carbon emissions, making them a critical aspect of modern urban planning (Bagheri et al., 2024).

In contrast, developing nations, including Nepal, face significant challenges in implementing energy efficiency regulations due to rapid urbanization, economic

constraints, and limited technical capacity. While the Nepal National Building Code (NBC, 2015) includes guidelines for energy-efficient construction, their adoption remains low. Studies indicate that traditional Nepali architecture inherently incorporates passive design elements such as thick masonry walls, internal courtyards, and strategically placed openings, which contribute to natural heating and cooling. However, the shift towards reinforced concrete structures with large glazed surfaces has led to increased energy demand for artificial cooling and heating. Despite efforts to promote sustainable construction, Nepal's urban landscape continues to evolve with limited integration of energy efficiency principles, highlighting the need for more comprehensive regulatory enforcement and awareness campaigns. The challenge remains in balancing modernization with the incorporation of passive design techniques to optimize energy use and enhance thermal comfort in residential buildings.

2.2 Passive Design Strategies

Passive design strategies focus on harnessing natural energy sources such as solar radiation, wind, and thermal mass to optimize indoor comfort. One of the key aspects of passive design is building orientation, which directly impacts solar heat gain and daylighting (Bodach et al., 2014). In colder climates, such as the mountainous regions of Nepal, buildings should be oriented to maximize solar exposure, particularly by placing larger windows on the south-facing façade. This allows passive solar heating during winter while minimizing heat loss. In contrast, in warmer regions like the Terai, the orientation should limit direct sun exposure, especially from the west, to reduce excessive indoor heat gain. Proper orientation not only improves thermal comfort but also reduces heating and cooling energy demands. Another critical factor is the window-to-wall ratio (WWR), which determines the amount of natural light entering the building and influences its overall energy performance. An optimal WWR, typically ranging between 20% to 35%, is essential for balancing natural lighting and minimizing heat loss or gain (Dewi et al., 2022; Sana et al., 2021; Shrestha & Uprety, 2023). In colder climates, a higher WWR on the south-facing façade can help maximize solar gain, while in warmer regions, a lower WWR or shading strategies can prevent excessive heat intake, thereby improving energy efficiency (Heidari et al., 2019). This balance between building orientation and WWR is fundamental to achieving energy efficiency in residential buildings.

2.2.1 Window Design and Window-to-Wall Ratio (WWR)

Choosing an appropriate window design is essential for balancing functional and aesthetic requirements. Windows significantly impact a building's daylighting, thermal performance, and energy efficiency. Large windows allow more daylight into a space, but they also increase heat gain or loss, influencing both heating and cooling demands (Hassan, 2016). Optimal daylight distribution, outdoor views, ventilation control, heat loss, and weather resistance are all important factors in window design (Merritt & Ricketts, 2000). Building codes typically require glass areas to cover at least 10% of each room's floor area, but a WWR exceeding 20% and positioning windows higher in the wall can enhance light penetration (Hassan, 2016).

The Window-to-Wall Ratio (WWR) is a critical design parameter that influences a building's energy performance. WWR is defined as the ratio of glazed area (Sg) to the total façade area (Sf), expressed as a percentage (Syed Fadzilb & Al-Tamimi, 2010).

$$WWR = \frac{S_g}{S_f}$$

A high WWR can improve daylighting and provide natural ventilation, but it may also increase energy consumption due to higher heating and cooling loads. Studies show that increasing WWR, particularly on south-facing façades, can reduce heating and lighting energy demand, but increase cooling energy consumption (Ghosh & Neogi, 2018). Optimizing WWR for different climatic conditions is essential for energy efficiency. For instance, research in Rajasthan found that a south orientation with a 15% WWR achieved a 41.8% reduction in solar gain and improved thermal comfort (Nair et al., 2014). Additionally, studies show that adjusting WWR can improve thermal comfort and reduce energy use by incorporating natural ventilation, especially in hot and humid climates (Syed Fadzilb & Al-Tamimi, 2010; Marino et al., 2017). Effective window design that considers WWR, glazing type, and orientation is essential to minimizing energy consumption while maximizing natural light and ventilation, thus contributing to more sustainable and energy-efficient buildings.

Location	**Lamahi, Dang Nepal**
Longitude	82 °
Latitude	27 °
Altitude	3,440 m

You have to fill out temperature, humidity and rainfall data for all months before you can make the evaluation!

Air temperature °C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	High	AMT (annual mean temp)
Monthly mean max.	71	80	88	98	92	95	89	88	85	88	80	72	98	85
Monthly mean min.	38	40	43	52	60	68	71	72	68	52	45	34	72	####
Monthly mean range	33	40	45	46	32	27	18	16	17	36	35	38	Low	AMR (annual mean range)

Relative humidity %	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean max am	100	97	95	95	99	98	100	100	100	100	100	100
Monthly mean min pm	32	26	19	19	15	38	63	65	62	45	43	34
Average	66	61.5	57	57	57	68	81.5	82.5	81	72.5	71.5	67
Humidity group	3	3	3	3	3	3	4	4	4	4	4	3

1 <30%
2 30–50%
3 50–70%
4 >70%

Rain and wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall mm	21	25	16	14	41	210	381	277	173	44	5	9	1216

Wind, prevailing	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Wind, secondary	E	NE	NE	NE	NE	NE	E	NE	NE	NE	NE	NE

N, NE, E, SE,
S, SW, W, NW

Diagnosis °C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AMT
Monthly mean max	71	80	88	98	92	95	89	88	85	88	80	72	85
Day comfort, upper	29	29	29	29	29	29	27	27	27	27	27	29	
Day comfort, lower	23	23	23	23	23	23	22	22	22	22	22	23	
Thermal stress, day	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	
Monthly mean min	38	40	43	52	60	68	71	72	68	52	45	34	
Night comfort, upper	23	23	23	23	23	23	21	21	21	21	21	23	
Night comfort, lower	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress, night	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	

H = Hot
O = Comfort
C = Cold

Comfort limits	AMT >20°C				AMT 15–20°C				AMT <15°C			
	Day		Night		Day		Night		Day		Night	
Humidity group	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	26	34	17	25	23	32	14	23	21	30	12	21
2	25	31	17	24	22	30	14	22	20	27	12	20
3	23	29	17	23	21	28	14	21	19	26	12	19
4	22	27	17	21	20	25	14	20	18	24	12	18

For AMT = 85

Day		Night	
L	U	L	U
26	34	17	25
25	31	17	24
23	29	17	23
22	27	17	21

Meaning	Indicator	Thermal stress Day	Thermal stress Night	Rainfall	Humidity group	Monthly mean range
Air movement essential	**H1**	H			4	
		H			2–3	<10°C
Air movement desirable	**H2**	O			4	
Rain protection necessary	**H3**			>200mm		
Thermal capacity necessary	**A1**				1–3	>10°C
Outdoor sleeping desirable	**A2**		H		1–2	
		H	O		1–2	>10°C
Protection from cold	**A3**	C				

Indicators	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
H1							1	1	1	1	1		5
H2													0
H3						1	1	1					3
A1	1	1	1	1	1	1						1	7
A2													0
A3													0

You have to fill out temperature, humidity and rainfall data for all months before you can make the evaluation!

Figure 4 Data input and Sample of Mahoney Table

The Mahoney Table is a valuable tool used for determining the appropriate WWR in building design. It helps optimize daylighting and thermal performance by providing guidance on the ideal WWR for different orientations and climatic conditions. The table primarily uses temperature and relative humidity data to provide design guideline

recommendations (Lamsal et al., 2021). In the Mahoney table, monthly average maximum and minimum temperature data can be tabulated, along with the corresponding relative humidity in the evening and morning. The Mahoney tables include six indicators (three for humidity, H1-H3, and three for aridity, A1-A3). These indicators are determined by heat stress (day and night), precipitation, relative humidity group, and the mean monthly temperature range. These indicators are tabulated for each month of the year and used to obtain data that indicate design recommendations (Koenigsberger et al., 2013).

2.2.2 Orientation

Building orientation is a critical factor in optimizing energy efficiency by influencing solar heat gain, daylighting, and thermal comfort. In colder climates, buildings should be oriented to maximize solar exposure, particularly with larger windows on the south-facing façade, to take advantage of passive solar heating during the winter months. This orientation helps minimize heat loss and reduces the need for additional heating (Bodach et al., 2014). In contrast, in warmer regions, such as the Terai, it is essential to minimize direct solar exposure, especially from the west, to avoid overheating and reduce cooling energy demands (Bodach et al., 2014).

Research has shown that optimizing building orientation can significantly reduce cooling energy consumption. For instance, buildings with a north-south orientation, minimizing the west-facing windows, have demonstrated lower energy demands in hot-humid climates (Chi et al., 2020). Additionally, building orientation is closely tied to natural daylighting, with well-oriented buildings benefiting from improved daylight penetration, reducing the need for artificial lighting and lowering energy consumption (Shrestha & Uprety, 2023). Overall, integrating proper building orientation into design strategies can enhance energy efficiency by minimizing the need for mechanical heating and cooling while improving indoor comfort.

2.3 Computer Simulations for Building Energy Performance

The use of building simulations has advanced significantly since the 1960s and has become a crucial tool for analyzing and predicting a building's thermal performance and energy consumption. Currently, there are more than 100 Building Energy Modeling Programs (BEMPs), including the U.S. Department of Energy's DOE-2 (DOE-2, 1980), Energy Plus (Crawley et al., 2001), and ESP-r (ESRU, 2002), developed by the

University of Strathclyde. BEMPs play a key role in the design of new building envelopes and HVAC systems, the retrofitting of existing buildings for energy savings, the development of codes and standards for energy-efficient design, and in supporting building energy rating and labeling programs (Zhu et al., 2012).

Computer modeling allows professionals, researchers, and students to predict the energy efficiency and environmental performance of buildings (Gado and Mohamed, 2014). It enables designers to visualize the relationship between a structure, its materials, and the surrounding environment, improving communication about building performance. Furthermore, simulation systems such as IES and Autodesk Ecotect help architects visualize invisible environmental factors in architectural spaces. These tools allow the integration of geometric data from CAD programs or directly from their 3D interfaces, offering a more accurate understanding of a building's environmental performance (Gado and Mohamed, 2014).

While computer simulations cannot replace the physical materials and components of a building, they do offer significant advantages for optimizing the design and its environmental performance. By optimizing building components and service systems, simulations have become an essential tool in architectural design, especially for achieving sustainable energy efficiency. Different simulation programs may use different software designs, algorithms, and user inputs to model the same building components, but all contribute to improving energy performance (Nimlyat, Dassah, & Allu, 2014). Some common simulation programs used to calculate energy efficiency in buildings are explained below.

Table 1 Energy simulation softwares

Software	Description
Urban Modelling Interface (UMI)	A specialized tool for urban-scale energy modeling, UMI integrates with Rhinoceros 3D and Grasshopper to assess energy efficiency at a neighborhood or city level. It enables simulations of building energy use, daylighting, walkability, and operational carbon emissions by incorporating climate data, material properties, and occupancy patterns. Its capability to analyze large-scale urban sustainability makes it particularly useful for town planning (UMI, 2020).

Energy Plus	A next-generation simulation tool combining DOE-2 and BLAST features, Energy Plus models heating, cooling, and ventilation energy use under various environmental conditions. It includes modular device simulation modules that enable third-party communication (EnergyPlus, 2020; Nimlyat, Dassah, & Allu, 2014).
Ecotect	A building design and environmental analysis tool that evaluates thermal and energy efficiency. While useful for parametric studies, its CIBSE Admittance Process-based thermal simulation engine has limitations, such as not accurately tracking solar radiation effects or accommodating extensive material libraries (CIBSE, 1999; Gado & Mohamed, 2014).
eQUEST	A widely used freeware energy analysis tool with an intuitive interface for professional-quality results. It integrates schematic and detailed building design assistants, an energy efficiency measure (EEM) wizard, and graphical result display module, based on the DOE-2 simulation system (eQUEST, 2020).
DOE-2	Developed in the 1970s by LBNL and J.J Hirsch & Associates, DOE-2 is a whole-building energy analysis software that estimates energy performance and life-cycle costs. It allows hourly simulations based on user-defined building configurations, materials, operational schedules, and climate data (DOE-2, 2020; Zhu, Hong, Yan, & Wang, 2012).
DesignBuilder	Built on Energy Plus, DesignBuilder provides a user-friendly interface for early-stage energy performance evaluation, carbon emissions analysis, solar shading visualization, and HVAC modeling. It helps architects and engineers optimize building comfort, daylighting, and ventilation strategies (DesignBuilder, 2020).
ESP-r	A transient energy simulation system modeling energy, air, and moisture flows while integrating control behaviors. It includes project management, database support, simulation tools, and CAD integration, allowing for complex multi-domain building performance analysis

	(ESRU, 2002; ESP-r, 2020).

2.3.1 Urban Modelling Interface (UMI)

Urban modeling and performance simulation have become essential tools for architects and urban designers seeking to optimize energy efficiency and environmental performance. The Urban Modeling Interface (UMI) offers an integrated platform for evaluating operational energy use, daylighting potential, outdoor comfort, and walkability in urban neighborhoods. Among its many applications, UMI facilitates the optimization of building orientation and WWR, two crucial factors that influence energy consumption, indoor comfort, and daylighting performance. Energy simulation tools like EnergyPlus and UMI optimize facade design and reduce energy demand (Pathirana et. al, 2019).

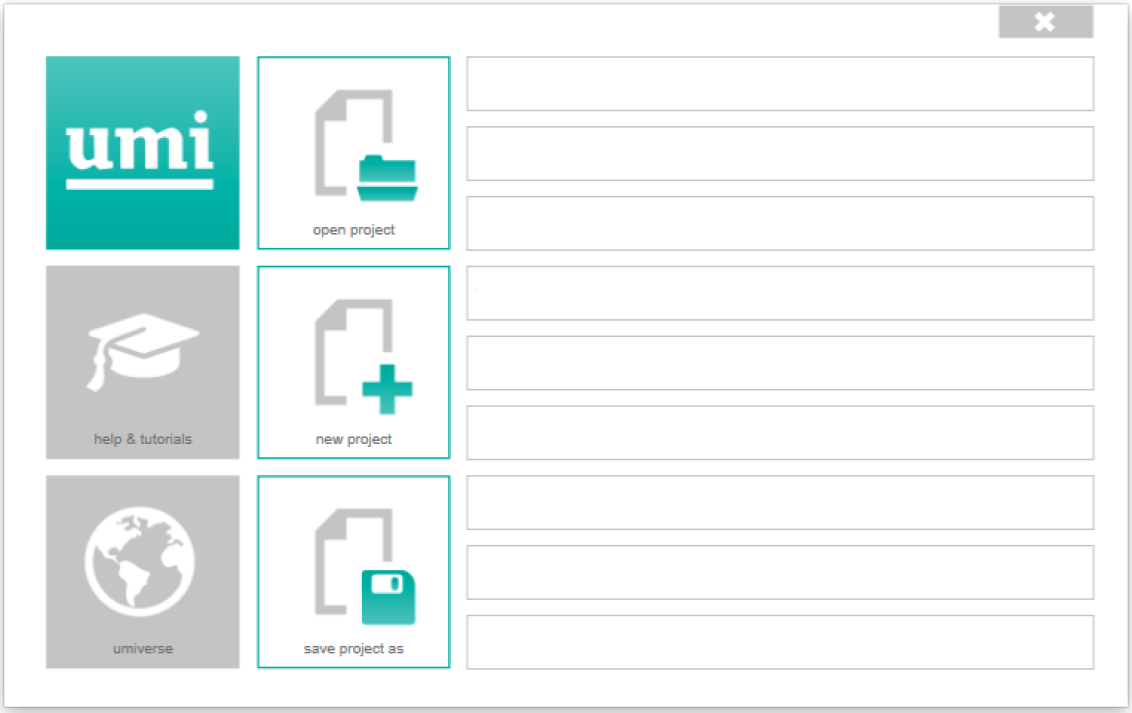

Figure 5 Welcome screen of UMI plugin in Rhino

i. Building Orientation Optimization in UMI

Building orientation significantly impacts heating and cooling loads, daylight availability, and solar gains. In UMI, designers can evaluate different orientation scenarios by leveraging its integration with EnergyPlus and Radiance-based daylight

modeling. The simulation process follows these steps:

Modeling the Geometry: Using Rhinoceros, users can define the massing and layout of buildings while setting their orientation parameters.

Assigning Material Properties: Each building in UMI is assigned specific construction templates that dictate thermal properties, infiltration rates, and shading characteristics.

Running Energy Simulations: EnergyPlus is used to simulate energy performance across different orientations, considering local climate data and urban heat island effects.

Analyzing Solar Gains and Heating/Cooling Loads: UMI outputs detailed visual and numerical data showing how orientation affects solar heat gain, cooling demand, and heating requirements.

Daylight Analysis: The daylighting module calculates daylight autonomy (DA) and continuous daylight autonomy (CDA), helping designers determine which orientations maximize useful daylight while minimizing glare.

Optimal building orientation varies by climate. In heating-dominated regions, maximizing southern exposure can reduce heating loads in winter, whereas in cooling-dominated climates, minimizing western exposure can mitigate overheating risks. Umi enables rapid iteration of these factors, allowing urban designers to balance energy efficiency and daylight access in different urban configurations.

ii. Window-to-Wall Ratio (WWR) Optimization

The window-to-wall ratio (WWR) is another critical parameter affecting building energy performance. A higher WWR increases daylight penetration but can also lead to excessive heat gains and losses. Umi provides a systematic approach to WWR optimization through the following steps:

Defining Facade Properties: Users specify the WWR for different facades, ensuring alignment with building use and orientation.

Simulating Energy and Daylight Performance: UMI generates EnergyPlus models to evaluate the impact of different WWR values on heating and cooling energy use.

Analyzing Daylighting Metrics: Radiance-based simulations determine how WWR

influences daylighting metrics like DA and cDA. Higher WWR values on well-oriented facades (e.g., south in the Northern Hemisphere) may improve daylighting without significantly increasing cooling loads if appropriate shading is applied.

Evaluating Thermal Comfort: UMI integrates indoor temperature data and occupant comfort models to assess how WWR adjustments influence occupant experience.

Shading and Glazing Strategies: To mitigate the risks of high WWR, UMI allows users to experiment with different glazing types, dynamic shading, and facade configurations.

iii. Key terminologies

Cumulative Daylight Autonomy (cDA) and Spatial Daylight Autonomy (sDA) are two key metrics used to evaluate daylight performance in buildings. cDA measures the percentage of time a space receives adequate daylight throughout the year, offering a broad perspective on overall daylight exposure. In contrast, sDA focuses on the percentage of floor area that maintains sufficient daylight levels typically 300 lux for at least 50% of the occupied hours in a year. While both metrics are useful for assessing daylight efficiency, they provide different insights into how natural light interacts with indoor spaces.

Metric	Definition	Value Range	Interpretation	Optimal Range
Cumulative Daylight Autonomy (cDA)	Measures the percentage of time a space receives adequate daylight throughout the year.	0% to 100%	• 0%: No sufficient daylight. • 100%: Space receives adequate daylight all year. • High values may cause glare and overheating.	50-80% for a balanced daylight exposure.
Spatial Daylight Autonomy	Measures the percentage of floor area that receives at	0% to 100%	• 0%: No floor area meets daylight sufficiency.	55-75% for optimal daylight

(sDA)	least 300 lux for 50% of the annual occupied hours.		• 100%: Entire floor area receives sufficient daylight. • Low values suggest reliance on artificial lighting.	distribution.
High cDA Values	Indicates areas receiving excessive daylight.	>80%	Excessive daylight can lead to glare and overheating.	Avoid areas with values >80%.
Low cDA Values	Indicates insufficient daylight in the space.	<50%	May require artificial lighting, increasing energy consumption.	Aim for values above 50%.
High sDA Values	Indicates good daylight penetration across the floor area.	>75%	More daylight reduces artificial lighting demand and improves energy efficiency.	Ideal value above 55%.
Low sDA Values	Indicates large portions of the floor area do not receive enough daylight.	<50%	Suggests need for artificial lighting and higher energy consumption.	Avoid values below 50%.

A higher cDA value, often represented by red areas in visualization models, suggests excessive daylight exposure in certain zones. While this can be beneficial for reducing artificial lighting demand, it may also lead to potential issues such as glare and overheating, especially in spaces with large windows or inadequate shading devices. Conversely, a predominance of blue areas in an sDA analysis indicates that much of the floor area does not receive sufficient daylight, meaning these areas may rely heavily on artificial lighting. Such results emphasize the importance of strategic daylighting design, balancing natural light penetration with glare control, shading elements, and window placement.

In daylight optimization strategies, architects and designers must carefully analyze both cDA and sDA results to ensure a comfortable and energy-efficient indoor environment. The goal is to maximize useful daylight while mitigating excessive exposure, which can be achieved through thoughtful building orientation, window-to-wall ratio (WWR) adjustments, and adaptive shading solutions.

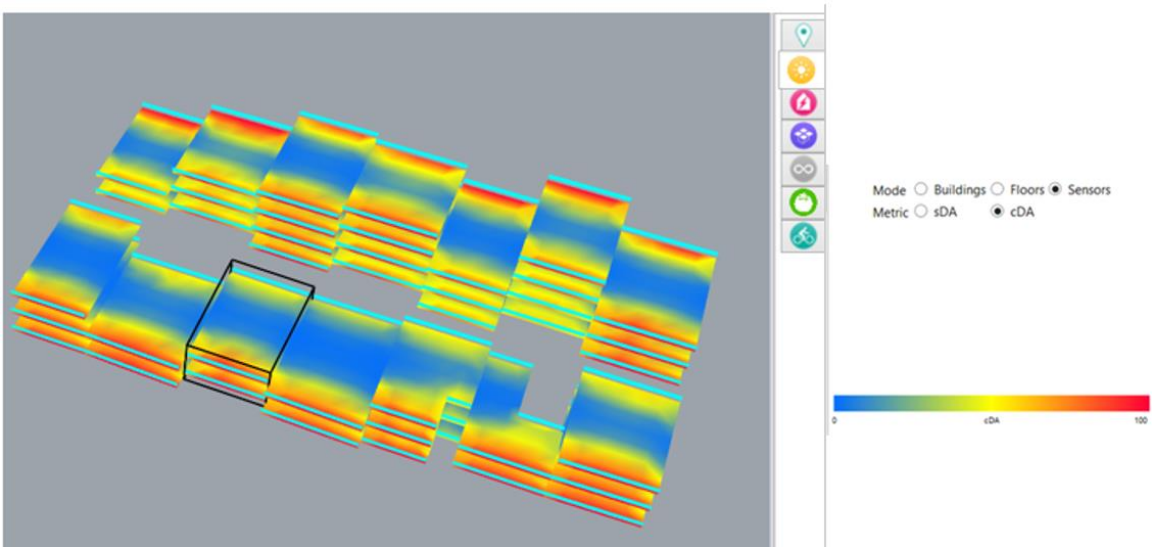

Figure 6 Output interface of UMI showing cDA value

The ideal WWR depends on multiple factors, including climate, facade orientation, and building function. For instance, a commercial building may benefit from a higher WWR to enhance daylighting in office spaces, while a residential building might require a more moderate WWR to balance privacy and energy efficiency.

UMI provides urban designers and architects with a powerful, data-driven approach to optimizing building orientation and WWR. By integrating energy simulation, daylight analysis, and urban microclimate modeling, UMI helps designers make informed decisions that enhance energy efficiency, daylight utilization, and occupant comfort. As cities move towards more sustainable and resilient urban planning, tools like UMI play a critical role in shaping efficient and livable built environments.

2.4 Review of previous literature

Habibi (2022) investigates the impact of building orientation on energy efficiency, particularly focusing on how different orientations affect Energy Use Intensity (EUI), heating, and cooling loads under varying climatic conditions. The study uses a combination of Rhino 3D with Grasshopper plugins (Ladybug and Honeybee) to model building geometry and climate input, and IES-VE for comprehensive energy

simulation. Two climate zones are considered: Austin, Texas, representing warm climates, and Minneapolis, Minnesota, representing cold climates. A single-story office building serves as the prototype, with simulations carried out at rotation intervals of 45°, resulting in eight distinct orientations for each climate.

The findings suggest that building orientation, although traditionally considered crucial, has a limited impact on energy performance when high-performance HVAC systems and insulation are already in place. Across all rotations, changes in EUI remained minimal, particularly in warm climates. For instance, the difference between the highest and lowest EUI due to orientation in Austin was found to be less than 3 kWh/m² per year. However, in colder climates like Minneapolis, some orientations showed a slight decrease in heating loads when windows faced south or southeast, aligning with passive solar heating principles.

The study employs an evolutionary optimization algorithm (Wallacei) to assess multiple parameters including window-to-wall ratio (WWR), infiltration rate, solar heat gain coefficient (SHGC), and orientation. The results show that infiltration and SHGC are more influential on EUI than orientation. In the cold climate scenario, optimized combinations resulted in a 39.57% reduction in energy consumption, demonstrating that while orientation alone might not significantly improve efficiency, its combined effect with envelope properties and ventilation strategies is substantial.

Habibi (2022) concludes that building orientation should be considered alongside other envelope performance parameters, especially in the early design stage. While orientation alone offers marginal gains in energy efficiency for well-insulated, mechanically cooled or heated buildings, it becomes a much more significant factor in naturally ventilated, low-energy designs. The research emphasizes that passive design strategies, including optimal orientation, must be integrated holistically with materials, ventilation, and façade design to achieve substantial energy savings.

Hong et al. (2024) present a detailed investigation into the relationship between residential building layouts and daylight availability in high-density urban environments, specifically within the context of China’s planning regulations. The study aims to assess the visual and non-visual daylight performance of living rooms across four housing estates located in different daylight climate zones: Tianjin, Wuhan, Chongqing, and Haikou. Using simulation tools ClimateStudio and ALFA, the research

evaluates several metrics including Daylight Factor (DF), Spatial Daylight Autonomy (sDA300,50%), Useful Daylight Illuminance (UDI), and melanopic Equivalent Daylight Illuminance (m-EDI), which address both visual comfort and circadian health. The methodology involves a comparative simulation approach where units were tested under overcast and clear sky conditions following both national (GB 50033) and international standards (LEED v4.1, WELL v2).

Findings reveal a significant discrepancy between planning regulations and actual daylight performance. A large proportion of units failed to meet the DF and sDA thresholds, especially in high-rise blocks where mutual obstruction between buildings limited daylight penetration. However, the study found relatively better performance under the UDI metric, indicating that while peak illuminance levels were not achieved, daylight was adequate and useful for large portions of the day. Moreover, even when visual metrics were unmet, many units demonstrated sufficient non-visual lighting conditions, with m-EDI values exceeding the recommended 250 lux threshold for circadian rhythm support—especially in sunlit climates like Haikou. These insights highlight that clear sky regions naturally enhance both visual and non-visual daylight potential even when planning layouts are suboptimal.

The research emphasizes the limitations of relying solely on traditional daylight metrics and regulations that do not consider climatic variation or building orientation. It critiques China's current daylighting code for its generalized approach and proposes a shift towards more context-sensitive standards that balance visual needs with health-centered lighting metrics. The study also advocates for planning reforms that take into account local daylight climates, the orientation of buildings, and urban density, suggesting that future residential designs incorporate both passive daylight strategies and active urban design planning to improve overall daylight accessibility. As residents spend increasing time indoors—especially in the wake of global health crises—the alignment of architectural design with both visual and biological daylight requirements becomes not only desirable but necessary.

Shrestha and Uprety (2023) investigate the influence of Window-to-Wall Ratio (WWR) on lighting energy consumption in public buildings, particularly through a case study of the Bharatpur Metropolitan Administration Block. Their research takes into account both visual comfort and energy efficiency, positioning daylighting as a crucial factor in occupant well-being and productivity. The authors explore various WWR scenarios

through field surveys and energy simulations using DesignBuilder, revealing that increasing the WWR enhances daylight penetration, thereby reducing dependence on artificial lighting.

Their analysis shows that a transition from a 10% to 30% WWR can yield up to 54% savings in lighting energy use, with diminishing returns beyond 30%, indicating it as the optimal WWR. The study breaks this down by floor, recommending 25% WWR for the ground floor and 30% for both the first and top floors, each aligning with points of lighting efficiency plateau.

Shrestha and Uprety (2023) highlight that WWR plays a critical role not only in lighting performance but also in thermal and air quality regulation, suggesting a need to balance visual comfort and cooling load, especially in warm climates. The paper references earlier simulation-based studies (Goia, 2016; Ayoosu et al., 2021) that similarly suggest WWR values around 30%–40% optimize energy performance without compromising indoor environmental quality.

The study emphasizes behavioral and structural implications by showing that appropriate daylighting strategies can reduce energy use without necessarily increasing mechanical cooling loads—provided optimal design choices like correct WWR and shading devices are adopted. By integrating climatic data, floor-specific design needs, and lighting simulations, the study promotes a more contextual and performance-based approach to architectural design in tropical and subtropical climates such as Chitwan.

Kaminska (2020) investigates the impact of building orientation on daylight availability and the associated potential for energy savings in educational buildings. The study compares daylight illuminance and electricity consumption for classrooms oriented towards the south-east and the north using both on/off and dimming control strategies for artificial lighting. It highlights the crucial role of building orientation and lighting control systems in achieving energy-efficient classroom design, particularly in climates like that of Poland where academic buildings are used predominantly outside summer months.

Kaminska (2020) identifies two lighting control strategies — a basic on/off approach and a more sophisticated dimming control strategy based on measured outdoor daylight illuminance. It is observed that while on/off control provides about 28% energy savings in south-east-oriented rooms, the savings drop to about 14% in north-facing classrooms.

In contrast, dimming control yields comparable savings of around 30-35% regardless of orientation, illustrating its effectiveness across diverse building orientations.

The study underscores the adaptive potential of dimming controls, particularly through tailored responses to daylight distribution within the classroom depth. Lamps are strategically dimmed or turned off based on real-time outdoor illuminance ranges (e.g., 7–9 klx, 9–12 klx, >12 klx), demonstrating a behavioural adaptation in building operations influenced by environmental sensing.

Kaminska also emphasizes the integration of technical systems with economic considerations, showing a two-year payback period for dimming systems despite higher initial costs, as compared to on/off systems with lower investment but also reduced savings. The study compares real consumption data with LENI (Lighting Energy Numeric Indicator) values from EN 15193-1:2017 and finds a high degree of correlation, validating the field data.

This research promotes the synergy between structural orientation, technological intervention, and occupant needs, aligning with broader sustainability goals. The findings advocate for lighting design in public buildings that maximizes daylight harvesting through intelligent control systems, enabling substantial reductions in lighting energy use while maintaining visual comfort and operational practicality.

Syed Fadzil et al. (2013) investigate the impact of varied building orientation and Wall Window Ratio (WWR) on daylight distribution in residential rooms within a tropical climate context, using the Fajar building at Universiti Sains Malaysia as a case study. The study responds to the Malaysian Uniform Building By-Laws (UBBL) which mandate a minimum of 10% window-to-floor area for daylight provision but do not stipulate an upper limit — a gap the authors argue may be problematic in Malaysia's bright and humid climate.

The research highlights that orientation plays a critical role in daylight availability, with east-facing rooms receiving higher illuminance levels in the morning and west-facing rooms peaking in the evening. Data was collected over 15 days using lux meters and analyzed for different WWR scenarios (50% and reduced to 25%). For east-facing rooms with 50% WWR, daylight factors ranged between 2–4%, and for west-facing rooms, 1–3%. These values surpassed the standard requirements outlined in the Malaysian Standard MS 1525. Upon reducing WWR to 25%, daylight factors fell to 1–

2% (east) and 0.5–1.5% (west), yet still generally met or exceeded standard illumination recommendations.

The study critiques the blanket assumption in existing by-laws that more glazing equates to better daylight performance. Instead, it warns against over-lit spaces, which may contribute to glare and overheating — particularly critical in equatorial regions. The authors recommend that the legal minimum for daylight openings should also have a reasonable upper threshold, suggesting that openings "not more than" 10% of floor area may be sufficient in such climates.

The findings reinforce the need for adaptive structural strategies (like WWR adjustments) that are climate-sensitive, and which balance daylight sufficiency with thermal comfort. Although primarily structural, the study indirectly reflects behavioral needs — i.e., designing spaces that prevent visual discomfort and reduce reliance on cooling systems.

De Luca et al. (2018) investigate the energy saving potential of daylight utilization in large single-floor retail buildings situated in cold climates such as Finland. The study emphasizes that daylighting not only reduces artificial lighting energy consumption but also positively affects occupant comfort and behavior. The researchers explored various combinations of skylights, clerestories, wall windows, glazing materials, and deflectors using dynamic simulations (Radiance, Daysim, IDA-ICE). Results show that electric light savings can reach up to 59% when using glass skylights and wall windows with multi-zone lighting controls. However, the absence of deflectors leads to excessive lighting and visual discomfort, while deflectors mitigate glare and reduce internal heat gains, slightly compromising daylight availability but enhancing occupant comfort.

De Luca et al. (2018) also highlight that polycarbonate skylights control excessive lighting better than glass but offer reduced daylight performance. Multi-zone lighting controls performed significantly better than single-zone, reducing electricity consumption by an average of 31%. The study points out the careful balance needed between increased daylighting and its impact on heating and cooling loads. While daylight reduces lighting loads, it can increase heating needs in winter and cooling needs in summer if not properly designed. The study confirms that optimized use of daylighting, particularly with well-planned zoning and lighting controls, is critical for achieving low-energy building design in commercial settings.

DeKay (2010) explores the fundamental question of how urban form would change if daylighting were considered a primary design criterion. The study introduces key principles such as the Daylight Access Rule, which relates street wall height to street width (H/W ratio), and emphasizes the need for building forms that allow consistent access to daylight. Using atrium buildings as a design basis, the study proposes Atrium Sizing Rules and Atrium Building Thickness Rules to maximize daylight penetration while considering development efficiency and energy use. For instance, to achieve 80-100% rentable area daylit, buildings should maintain a thickness of 6-7 times the window-head height (6h-7h).

DeKay (2010) highlights that building height and latitude significantly affect atrium sizing, and that wider, more numerous atria are required in higher latitudes due to lower daylight availability. The study quantifies these spatial needs and uses matrix analyses to guide appropriate massing. It also introduces the Daylight Envelope concept, which limits building bulk to ensure daylight access for neighboring structures, effectively shaping a pyramidal zoning limit based on solar geometry and H/W ratios. The study suggests that block and street patterns should be designed to support these daylight-friendly building forms, such as single- or multiple-atria buildings, and that existing city grids (like those in Eugene, Portland, and Seattle) can either support or limit effective daylight planning depending on block size and orientation.

DeKay (2010) concludes that cities should adopt urban forms that facilitate ecological strategies like daylighting to remain sustainable as fossil fuel dependence wanes. The study demonstrates this approach in a case study of downtown Chattanooga, where daylight envelopes were applied to assess current development and propose future urban growth models that balance density, aesthetics, and daylight access. The author emphasizes that if cities prioritize light access, they can enhance livability, reduce energy consumption, and support long-term ecological integrity.

Yassin, Sheta, and Elwazir (2017) examine how variations in Window-Wall Ratio (WWR) influence daylighting performance in residential buildings under the constraints of Egyptian construction law. The study focuses on a multi-story apartment complex in Mansoura City and explores passive design strategies to optimize daylight access, aiming to reduce artificial lighting demand and improve indoor environmental quality. Using Rhino and the DIVA plugin, the study simulates daylight performance under various WWR scenarios, façade orientations, and obstruction heights to evaluate

compliance with daylight autonomy (DA) thresholds—specifically, achieving at least 300 lux during 50% of occupancy hours.

The study analyzes a typical living room with dimensions of 5.4m × 3.6m × 2.7m, and simulates daylight levels for WWRs ranging from 16% to 80%. Results show that daylight autonomy improves significantly with higher WWR, but the angle of obstruction (caused by opposite buildings) critically affects daylight penetration. For instance, at WWR = 16%, DA meets the required threshold only when the opposing building creates a barrier angle less than or equal to 20°. For WWR = 30%, acceptable DA levels are achieved up to a 45° barrier angle, while WWR = 60% supports up to 58°, and WWR = 80% supports up to 60°. The findings reveal that higher WWRs allow for greater tolerance to external obstructions without compromising indoor daylight levels.

Yassin et al. (2017) also critique the Egyptian Building Law No. 119 (2008), which allows residential buildings to rise to 1.5 times the street width—an approach that, according to their findings, could result in inadequate daylight levels on lower floors. For an 8m-wide street, their simulations show that daylight requirements are only satisfied up to a building height of five floors, corresponding to a building height 2.1 times the street width—highlighting a discrepancy between legal allowances and daylighting performance.

The study concludes by recommending the integration of daylight simulation tools during early design stages to better inform decisions regarding WWR and urban form. It advocates for revising planning regulations to ensure daylight accessibility based on performance criteria rather than rigid height-to-width ratios, thereby supporting healthier and more energy-efficient living environments.

Esfanjary (2015) investigates the evolution of urban morphology in the Persian city of Maibud, demonstrating how the city's form evolved over centuries through environmental, topographical, and cultural adaptations. The study emphasizes adaptation strategies in urban form rather than large-scale interventions, showcasing a long tradition of incremental, organic development within environmental constraints.

The author identifies two primary morphological responses in Maibud: the twisting alley system (Sakhtar-i Mahalla Bala) and the orthogonal street network (Sakhtar-i Mahalla Pa'in). The former, associated with earlier settlements on elevated and water-

scarce terrains, highlights compact urban forms with narrow, winding paths adapted to topography and defense. The latter, emerging during the Islamic period, particularly under the Muzaffarid dynasty, reflects structural and spatial adaptations for increased water accessibility, openness, and greening, enabled by surface qanats.

Esfanjary notes that environmental adaptation is visible in the use of mud-brick architecture, which, although perceived as temporary, allowed for greater flexibility, adaptability, and maintenance, contributing to the durability of Maibud's urban form. The study argues that this material choice supported incremental behavioral and structural modifications, preserving street patterns and plot boundaries over centuries.

The research also discusses how social and technological synergy influenced urban development. For example, the interdependence between street layout and water access defined plot sizes, orientations, and building configurations. The paper highlights how property boundaries and water rights shaped residential growth patterns, and how adaptive reuse of space (like the integration of private alleys or "darbands" into the public network) showcases an organic form of planning rooted in behavioral negotiation and environmental interaction.

The placement of the Jami mosque at the transitional zone between old and new street systems symbolizes the urban shift from pre-Islamic to Islamic planning paradigms, integrating spiritual, social, and physical dimensions of the evolving city. Similar to adaptive thermal comfort studies in modern contexts, the residents of Maibud historically adapted their urban layouts, building forms, and behaviors in response to the harsh arid environment, without reliance on external technological interventions.

Ultimately, Esfanjary (2015) emphasizes the importance of historical continuity, passive strategies, and socio-environmental resilience in urban development, proposing that Maibud's form endures because of its deep-rooted adaptive strategies that blend environmental necessity with cultural practice.

Tawfeeq and Qaradaghi (2024) investigate passive design strategies through the lens of optimizing the Window-to-Wall Ratio (WWR) to reduce energy use intensity (EUI) in low-rise residential buildings in the hot summer Mediterranean climate of Sulaimaniyah City, Iraq. The study adopts a mitigation approach by targeting architectural form and envelope characteristics to enhance building intelligence and energy performance.

The authors emphasize that WWR plays a pivotal role in energy consumption, often more significantly than wall thickness, highlighting the importance of early design-stage decisions. The research utilizes Autodesk Revit 2024 and Insight Cloud to simulate the performance of five different residential blocks, varying the WWR from 0% to 95% across four cardinal orientations.

The findings indicate that energy performance is orientation-sensitive. For southern-facing façades, EUI reductions ranged from 1.23 to 14.98 kWh/m², while northern façades exhibited energy losses between 2.03 and 12.98 kWh/m². The study proposes optimal WWRs of 65% for southern and eastern façades, 95% for northern, and 30% for western façades—showing that strategic variation by orientation enhances thermal performance and supports intelligent energy management.

The research further integrates technological and behavioral intelligence through the use of BIM platforms, simulating occupant-centric, real-time adaptation scenarios. These strategies resonate with the concept of "passive intelligence", where architectural elements preemptively respond to environmental stressors, minimizing active energy input.

Studies referenced within the paper (e.g., Alwetaishi 2019; Alghoul et al. 2017; Pino et al.; Gasparella et al. 2011) further reinforce the idea that WWR strongly influences cooling loads, and that orientation-specific glazing can either mitigate or intensify these loads. For instance, south-facing glazing can reduce heating demand via passive solar gains, but may exacerbate cooling loads in hot climates. The research echoes findings from Persson et al. (2006) that resizing windows according to façade orientation significantly affects both thermal and visual comfort.

Ultimately, Tawfeeq and Qaradaghi (2024) argue for climate-specific and façade-specific WWR optimization as a cost-effective, passive design strategy that aligns with intelligent building principles and supports broader sustainability goals. They recommend embedding such strategies into early-stage design workflows, especially in climate zones vulnerable to overheating and high cooling demands.

Elghamry and Azmy (2017) examine the influence of building orientation on energy consumption in Cairo’s hot arid climate, utilizing EnergyPlus simulations to explore passive design strategies. Their work reflects both mitigation and adaptation approaches, focusing on orientational alignment and envelope treatment to reduce

cooling and heating loads and optimize thermal comfort.

The study emphasizes passive solar design as a core mitigation strategy, favoring orientation and envelope efficiency over costly active systems. Key passive measures explored include orientation optimization, window-to-wall ratio control, shading systems, thermal insulation, and glass specifications. The paper argues that southern orientations offer the best energy efficiency, especially in winter due to enhanced solar gain, while western facades result in the highest annual energy use, increasing cooling loads significantly—by up to 26% more than southern-facing façades.

Their analysis includes rotational orientation simulations at 15° intervals, showing that a north–south axis offers the lowest annual energy use. Cooling loads were predominant in Cairo's energy profile, with lighting remaining relatively constant across all orientations. The study confirms that heating and cooling loads are highly sensitive to orientation, and orientation offsets of just 15–30° from north–south still maintain energy efficiency within acceptable ranges (less than 5% deviation).

The authors further analyze compound room models (a chain of repeated room units) and conclude that when oriented north–south, such configurations reduce energy consumption by 9–13% annually compared to east–west orientations. This suggests not only the behavioral importance of orientation in design, but also economic impacts, translating into substantial cost savings across building floors and types, particularly for residential and hotel applications.

The study supports integration of urban planning strategies that align road and building layouts along energy-optimal orientations. It advocates for early-stage design decisions rooted in environmental context, local climate response, and architectural intelligence, reinforcing the role of simple passive adjustments in achieving thermal comfort and sustainability with minimal reliance on mechanical systems.

Ghiai and Mahdavinia (2014) investigate the relationship between Window to Wall Ratio (W.W.R) and energy consumption in high-rise office buildings in Tehran. The study uses eQUEST software to simulate energy use across different W.W.Rs—ranging from 100% to 20%—and finds a direct correlation: reducing the W.W.R leads to a significant decrease in annual energy consumption. A 20% W.W.R results in a 17% reduction in total energy use. The research also evaluates side-to-side façade orientation impacts, showing the highest energy-saving potential on the southern façade (up to 7%

reduction), followed by eastern (5%), western (4%), and northern (2%) orientations. The findings emphasize the importance of strategic envelope design, particularly optimizing W.W.R based on orientation, as a passive energy-saving measure in high-rise office buildings. The study suggests that a W.W.R between 20%–40% is most effective, with lower ratios showing diminishing returns on certain façades. It highlights the relevance of climatic adaptability in façade design and supports the integration of architectural strategies with energy performance considerations for sustainable building development in Tehran.

Asfour and Alshawaf (2015) examine the influence of housing density on the energy efficiency of residential buildings in hot climates. Using computer simulations via Ecotect and Design Builder software, they modeled multiple configurations of detached, row, low-rise, and high-rise apartment buildings in Al-Arish, Egypt. The study reveals a clear trend: increasing housing density generally leads to higher energy consumption, especially due to increased cooling loads in hot climates. Among the tested configurations, row houses showed the best energy performance, reducing average energy consumption by up to 28% compared to high-rise apartments. This is attributed to their compact horizontal form, which minimizes solar gains and maximizes surface area efficiency. The study highlights that energy loads are influenced not only by housing type and density, but also by orientation and urban form. East-West orientations performed better than North-South ones due to reduced exposure to solar radiation. The research underscores the importance of low-rise, compact planning strategies in achieving thermal comfort and energy efficiency in hot climate regions, and recommends further modeling and experimental studies for broader climatic contexts.

Goia (2016) explores the optimal Window-to-Wall Ratio (WWR) in office buildings across four different European climates—Oslo, Frankfurt, Rome, and Athens—using integrated thermal and lighting simulations. The study aims to minimize total energy use by balancing heating, cooling, and lighting demands. Findings indicate that while optimal WWRs vary with orientation and climate, most fall within a narrow range ($0.30 < WWR < 0.45$), except for south-facing façades in very cold or hot climates. South façades in cold climates benefit from larger windows for passive solar heating, while in hot climates, smaller windows reduce cooling loads. Sensitivity analyses show that optimal WWRs are influenced by building compactness (SA:V), HVAC system

efficiency (SCOP), and artificial lighting efficacy. Results also highlight the non-linear relationship between energy use and WWR, and underscore the importance of integrated façade design, considering daylight autonomy (DA) and glare risk (UDI>2000). The study concludes that early-stage selection of WWR should be energy-informed and context-specific, offering rule-of-thumb ranges to guide designers toward low-energy building envelopes.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Research Paradigm

The research paradigm serves as a philosophical framework that guides the underlying theories, methodologies, and epistemological stance of a study. It shapes how researchers perceive the world, how they interpret data, and what they consider to be valid knowledge (Guba & Lincoln, 1994). Essentially, it defines the approach and assumptions that underpin the entire research process, influencing the selection of research methods, data collection strategies, and modes of analysis. In this study, a mixed-methods case study approach is employed within the pragmatic research paradigm. Pragmatism, as a research paradigm, emphasizes the importance of practical consequences and real-world applications of research findings (Morgan, 2007). It encourages the integration of both qualitative and quantitative methods to gain a more holistic understanding of complex research problems.

According to Creswell (2003), the pragmatic paradigm supports methodological pluralism, allowing researchers to draw upon diverse tools and techniques best suited to address the research objectives. This flexibility is particularly valuable in studies involving multifaceted systems such as building performance analysis. By combining empirical data from simulations with context-specific qualitative insights, the study can address both the technical and experiential dimensions of the research question. The current study aims to optimize the window-to-wall ratio (WWR) and building orientation for improved energy efficiency through the use of computer-aided simulation tools such as EnergyPlus and DesignBuilder. This aligns with the pragmatic approach, which seeks to generate actionable knowledge that can inform design decisions and policy recommendations in the built environment (Teddlie & Tashakkori, 2009). Therefore, the pragmatic paradigm is well-suited for this research, as it allows for an evidence-based, context-aware exploration of sustainable architectural strategies.

3.2 Research Philosophy

The study's **ontological assumption** is grounded in the belief that reality is shaped by the interaction between physical environments and human decisions, particularly in the context of urban development. It acknowledges that many urban development projects often neglect critical aspects of energy efficiency, largely due to limited awareness, lack of technical expertise, and the absence of enforceable energy policies or regulatory

frameworks (UN-Habitat, 2016). As a result, buildings within such developments frequently exhibit high levels of energy consumption, contributing to increased greenhouse gas emissions and long-term operational costs. Urban planners and architects often prioritize immediate concerns such as land-use efficiency, transportation networks, and basic infrastructure development, while overlooking the energy performance of buildings as an integral part of sustainable urban design. This ontological stance underscores the importance of recognizing buildings not as isolated structures, but as dynamic components of the broader urban ecosystem that both influence and are influenced by energy-related decisions.

From an **epistemological perspective**, the study is rooted in the belief that valid knowledge emerges from applied, empirical methods—specifically, the use of simulations, modeling, and data-driven analysis. This view aligns with the pragmatic research paradigm, which values knowledge derived from tools that help solve practical problems (Creswell & Plano Clark, 2011). The research relies on computational modeling to explore real-world scenarios involving the window-to-wall ratio (WWR) and building orientation, both of which are critical parameters affecting energy performance. Tools such as EnergyPlus and DesignBuilder are employed to simulate thermal behavior, daylight availability, and energy demand, providing measurable outcomes that reflect the performance of different design configurations. These simulations enable the identification of optimal design strategies that balance energy efficiency with user comfort.

Furthermore, this approach supports the notion that knowledge is iterative and situational, evolving through the interaction between design hypotheses and performance data. By generating simulation-based evidence, the study contributes to a growing body of knowledge aimed at informing energy-efficient design practices and sustainable urban policy-making (Attia, 2018). This reinforces the epistemological position that knowledge should be actionable and grounded in technological application rather than abstract theorization. Ultimately, this research aspires to bridge the gap between architectural design, urban planning, and environmental performance by using computational tools to produce insights with direct applicability to contemporary urban challenges.

3.3 Research Design

The study adopts a **mixed-method research approach**, integrating both qualitative and quantitative methods to comprehensively address the research objectives. This methodological pluralism allows for a richer, more nuanced exploration of the interplay between building orientation, window-to-wall ratio (WWR), and energy efficiency. By employing both empirical data and contextual interpretation, the study ensures a balanced perspective that captures technical, environmental, and design-related dimensions of building performance. This integration enhances the reliability and validity of the findings by triangulating results from diverse sources and methodologies (Tashakkori & Teddlie, 2010).

The quantitative aspect of the study is primarily conducted through computer-based simulations using tools like EnergyPlus and DesignBuilder. These tools are capable of modeling thermal behavior, solar gain, daylighting, and energy consumption across a variety of scenarios, enabling the identification of optimal WWR and orientation strategies under different climatic conditions. The simulations provide precise, numerical data that can be analyzed to evaluate the impact of design choices on heating and cooling loads, indoor comfort levels, and daylight availability (Attia et al., 2012). Meanwhile, the qualitative dimension involves literature review and case study analysis of existing buildings, policies, and design standards. These sources provide contextual insights that help interpret simulation results and relate them to real-world practices and constraints.

By combining these approaches, the research not only evaluates technical performance but also considers broader architectural and planning implications. This aligns with the pragmatic paradigm, which advocates for practical, outcome-oriented research that can inform actionable design strategies (Creswell & Plano Clark, 2011). The mixed-method design thus supports a holistic understanding of how WWR and orientation can be strategically manipulated to optimize energy performance, enhance thermal comfort, and promote sustainable building design within the urban context.

3.3.1 Qualitative Method

The qualitative approach in this study is instrumental in gaining contextual and interpretive insights into design considerations, especially in relation to energy efficiency, building orientation, and user preferences. This component goes beyond

numerical data, allowing for a deeper exploration of the environmental, social, and cultural factors that shape building design. By engaging with human perspectives and environmental observations, the qualitative methods help contextualize the outcomes of computer simulations, offering a more holistic understanding of the factors influencing sustainable building practices (Denzin & Lincoln, 2011). Through qualitative inquiry, the study also captures the nuances of local practices, behavioral patterns, and planning priorities that may not be immediately evident through quantitative analysis alone.

Literature Review: The literature review formed a foundational aspect of this qualitative process. An extensive survey of academic research, technical reports, and national and international guidelines was undertaken to construct a robust theoretical and practical framework. The literature covered key areas such as passive design strategies, optimal window-to-wall ratios (WWR) across various climatic zones, solar orientation principles, and integrated energy-efficient building systems (Reinhart & Davila, 2016). Documents such as the ASHRAE standards, NBC (National Building Code of Nepal), and the Passive House guidelines provided baseline parameters for design evaluation. This review not only offered insights into the scientific basis of WWR and orientation optimization but also highlighted best practices and innovations in sustainable architectural planning.

Site Observation: Site observation played a critical role in grounding the study within a real-world setting. Field visits were conducted in Lamahi Municipality, where firsthand data was collected to assess how current development patterns affect building design and energy use. Observations focused on prevalent building types, architectural orientation, facade treatments, and typical WWRs. These observations were essential for validating the relevance and applicability of simulation scenarios. Furthermore, qualitative interviews and informal discussions were held with local stakeholders, including municipal planners, architects, and real estate developers. These engagements revealed key insights into existing urban planning processes, regulatory limitations, and the level of awareness regarding energy-efficient design practices within local development initiatives. Stakeholders also highlighted constraints such as budget limitations, land use pressures, and limited access to design tools or training, which impact the adoption of sustainable strategies.

3.3.2 Quantitative Method

The **quantitative approach** in this study served as a fundamental means for gathering, analyzing, and interpreting numerical data related to energy consumption and efficiency in the case study area of Lamahi Municipality. The core aim of this approach was to quantify energy usage patterns in residential buildings and use this information to support evidence-based decision-making for optimizing building design parameters such as window-to-wall ratio (WWR) and orientation. Through rigorous data collection and computer-aided modeling, the study sought to develop predictive insights into how varying design strategies can influence energy performance. Quantitative data not only provided measurable outcomes for comparison but also enhanced the objectivity and replicability of the research findings, in line with the principles of post-positivist inquiry (Babbie, 2020).

Energy Consumption Pattern Survey: A detailed **energy consumption survey** was designed and conducted across selected residential buildings in Lamahi. The survey aimed to capture household energy use specific to heating, cooling, lighting, and appliance loads. Structured questionnaires were administered to gather monthly and seasonal electricity usage data, categorized by end-use application. Respondents were also asked to describe behavioral patterns related to energy consumption, such as preferred indoor temperatures, use of shading devices, and duration of artificial lighting usage during the day. Furthermore, questions were included to assess user satisfaction with their current building's performance in terms of thermal comfort, natural lighting, and energy bills.

The collected data was essential in establishing a baseline for simulation models. It enabled the calculation of energy use intensity (EUI)—a critical metric expressing energy consumption per square meter of building area—which served as a key performance indicator (KPI) in evaluating the effectiveness of alternative design scenarios. Additionally, the survey revealed gaps in energy-efficient behaviors and pointed to a lack of awareness about passive design strategies among local residents.

Computer Simulation: Building on the insights derived from the survey and literature review, a base simulation model of a typical residential unit in Lamahi was developed using the Urban Modeling Interface (UMI) tool, which integrates energy modeling with urban-scale design strategies. The model was calibrated using real-world data to ensure its representativeness and accuracy. Various scenarios were simulated by systematically altering the WWR and building orientation to assess their impact on total

energy demand. Parameters such as glazing properties, insulation levels, and indoor temperature setpoints were standardized across all models to isolate the effects of WWR and orientation.

Each simulation generated outputs related to annual energy consumption for heating, cooling, and lighting, as well as data on thermal comfort and daylight availability. The results were analyzed statistically to identify trends and determine the optimal WWR and orientation configurations that minimize energy usage while maintaining user comfort. The simulations demonstrated, for example, that south-facing buildings with moderate WWR (between 30–45%) achieved better energy performance in Lamahi's climatic context compared to other orientations or larger glazed areas. These findings were consistent with other studies on energy-efficient facade design in similar climatic zones (Attia et al., 2012).

The quantitative results from the simulation offered precise, actionable data that could inform architectural decision-making and local policy development. Moreover, they helped to validate the initial hypothesis that design parameters such as WWR and orientation significantly influence energy efficiency and could be optimized to reduce operational energy demand without compromising comfort or aesthetics.

3.4 Research Methodology

The research methodology for this study was carried out in three main stages, combining both qualitative and quantitative approaches to optimize the window-to-wall ratio (WWR) and orientation for energy efficiency using computer simulations.

3.4.1 First Stage

The research commenced with a comprehensive and in-depth review of existing literature on energy efficiency, window-to-wall ratio (WWR), building orientation, and simulation-based approaches to analyzing building energy performance. This stage served as the intellectual foundation of the study, ensuring that the research was grounded in established knowledge while also identifying gaps that needed to be addressed. A wide range of academic sources, including peer-reviewed journal articles, books, technical papers, and case studies, were examined to understand the principles of energy-efficient building design and the role of passive solar strategies in reducing energy demand.

Particular attention was given to literature focusing on the impact of WWR and building

orientation on energy use, thermal comfort, and daylighting, especially in climates similar to that of the case study area. This helped the study understand how façade design and spatial orientation affect indoor environmental quality and operational energy demand. Studies involving computational modeling and performance-based simulations were also analyzed to gain insight into appropriate tools, input parameters, and performance metrics for the simulation phase of the research.

In addition to academic literature, the review also covered policy documents, energy guidelines, building codes, and national strategies relevant to energy-efficient urban development. This included standards that guide building design practices and promote sustainability, helping to situate the research within its regulatory and institutional context. Reviewing these documents helped to ensure that the proposed methods and design recommendations would align with existing frameworks and potentially inform policy improvements.

This literature review phase not only informed the theoretical background of the research but also played a vital role in shaping the formulation of research questions, hypotheses, and the methodological framework. It helped refine the scope of the study, identify appropriate variables for analysis, and clarify the significance of the selected simulation scenarios. Overall, this stage laid the groundwork for a focused, well-informed investigation into the optimization of WWR and orientation for enhanced building energy performance.

3.4.2 Second Stage

The second stage of the research focused on the identification of a suitable case study area and the systematic collection of data to support the simulation process. Lamahi town planning area, located in Ratodada, Lamahi, Dang, was selected as the case study site due to its growing urban character, relevance to energy consumption trends in developing urban centers, and potential for the application of sustainable design interventions. Lamahi represents a typical mid-sized town in Nepal undergoing rapid urbanization, making it a fitting context for studying the energy implications of building orientation and window-to-wall ratio (WWR) in real-life urban development scenarios.

This stage incorporated both field-based and survey-based methods of data collection to ensure a well-rounded understanding of the site. Site observations were conducted to assess the urban form, street layout, building typologies, façade treatments, shading

elements, and orientation patterns commonly observed in the built environment. These direct observations helped in mapping the architectural and planning characteristics of the area, including construction materials, WWR variations, and the spatial organization of buildings within residential plots.

To complement the visual and spatial assessment, an energy consumption survey was carried out with local residents. The survey gathered household-level data on electricity usage, primarily for heating, cooling, and lighting. In addition to quantitative consumption values, residents provided insights into their daily energy-use habits, such as use of fans or heaters, natural ventilation practices, reliance on artificial lighting, and perceived comfort levels throughout the year. The objective was to gather empirical data on energy consumption per unit floor area, which would serve as a baseline for building energy modeling and simulation tasks.

Furthermore, the study collected climatic data from both local meteorological offices and publicly available resources such as the EnergyPlus database in the form of **.**epw files. These datasets included hourly values of solar radiation, air temperature, humidity, and wind speed, which were crucial inputs for simulation tools. The collected climate data was also analyzed using the Mahoney Table method, a climatic analysis tool used to determine passive design recommendations based on temperature and humidity patterns. This helped in evaluating Lamahi's climatic suitability for various passive strategies such as solar orientation, natural ventilation, and thermal mass use.

By combining local energy use behavior, site-specific environmental observations, and climate-responsive data, this stage created a strong empirical foundation for the subsequent simulation and analysis phase. The multi-source data collection approach ensured that the simulation models would accurately reflect real-world conditions, thereby increasing the validity and applicability of the study's results.

3.4.3 Third Stage

The final stage of the research involved integrating all collected data into a simulation-based analytical framework to evaluate the energy performance of different building design scenarios and draw meaningful conclusions. This phase marked the transition from empirical data collection to computational modeling and decision-making. All the information gathered from the literature review, household energy consumption surveys, stakeholder discussions, and on-site observations was synthesized and input

into simulation software to ensure the models accurately reflected the environmental, social, and physical context of the study area.

The simulations were carried out using UMI (Urban Modeling Interface), a Rhino-based energy modeling tool capable of assessing building energy use, daylighting, and thermal comfort in urban settings. UMI was selected for its ability to model energy consumption at both the individual building and neighborhood scale, allowing for a holistic assessment of design strategies. In this stage, a series of digital building prototypes were created, representing typical residential structures in Lamahi. These models were then modified to reflect different values of window-to-wall ratio (WWR) and building orientation, serving as the basis for testing the energy performance of each design scenario.

The modeling process involved simulating multiple design iterations, each with variations in window size, placement, wall insulation, glazing properties, and the angle of building orientation relative to the sun path. These adjustments enabled a detailed analysis of how specific design decisions affected annual energy demand for heating, cooling, and artificial lighting. Simultaneously, the models assessed daylighting performance, evaluating the extent to which natural light could meet indoor lighting needs during different seasons and times of day.

The outputs of these simulations provided valuable insights into the trade-offs between energy efficiency and visual comfort. The study identified design combinations that minimized energy consumption while ensuring adequate access to daylight and acceptable indoor thermal conditions. For instance, models with moderate WWRs facing south or southeast typically demonstrated reduced cooling loads in summer and improved daylight penetration throughout the year. The performance data generated through UMI also allowed the identification of design thresholds beyond which energy consumption began to rise significantly—information critical for setting practical design guidelines.

In addition to single-building analysis, the simulations were extended to assess how the orientation of buildings across a neighborhood block could influence collective energy demand, highlighting opportunities for urban-scale energy efficiency improvements. The results of this final phase were then analyzed to formulate conclusions and design recommendations that are climate-responsive, energy-efficient, and contextually

appropriate for Lamahi and similar urban areas. Ultimately, this stage reinforced the study's goal of using computer simulations not just as a theoretical tool, but as a practical decision-support mechanism for improving urban building design.

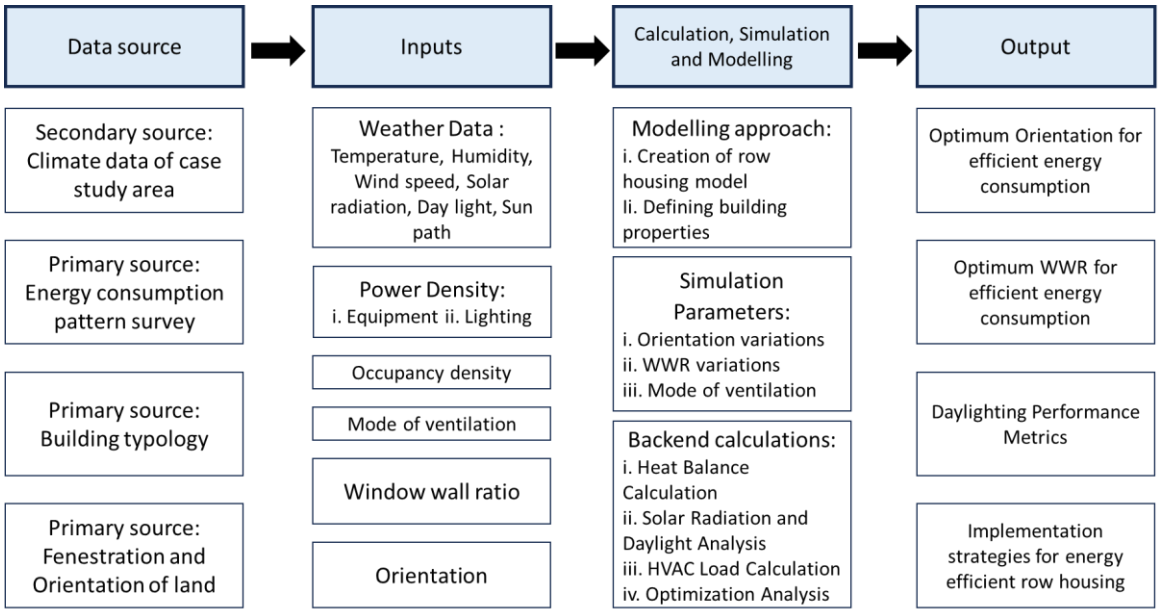

Figure 7 Architecture of simulation

Figure 7 represents a comprehensive Architecture of Simulation used in the study to evaluate and optimize building design parameters—specifically building orientation and window-to-wall ratio (WWR)—for improved energy efficiency. The figure is structured across four key components: Data Source, Inputs, Calculation, Simulation and Modelling, and Output, each reflecting a phase in the research process and collectively illustrating how various types of data and methods contribute to the overall analysis.

The first column, Data Source, outlines the origin of the information used in the research. These sources include literature reviews, field observations, surveys and questionnaires, stakeholder discussions, and climatic data in the form of .epw files from the EnergyPlus weather database. Literature reviews provide theoretical grounding and global best practices on energy efficiency and building performance. Field observations and surveys offer empirical data about the existing built environment, energy use behavior, and construction typologies in the case study area. Discussions with stakeholders such as planners, developers, and residents provide contextual insights and help understand current challenges and levels of awareness. Weather data is essential for climate-responsive design simulations.

The second column, Inputs, captures the parameters derived from the data sources that are used in the analysis. These include information on energy consumption patterns, local construction materials and techniques, building orientation and spatial layout, WWR, climatic conditions (such as temperature, humidity, and solar radiation), and passive design features commonly observed or suggested. These inputs are critical in developing simulation models that accurately reflect both the physical and environmental realities of the study area.

In the third column, Calculation, Simulation and Modelling, the study employs advanced computational tools and methods to process the inputs and evaluate building performance. This includes energy modeling using the Urban Modeling Interface (UMI), a Rhino-based simulation tool designed to assess energy consumption, daylighting, and thermal comfort. The Mahoney Table is also used for climate analysis, helping identify passive design strategies suited to the local climate. Several scenarios are tested by varying WWR and orientation to understand their impact on energy demand and indoor environmental quality. This iterative modeling approach enables the identification of optimal building configurations.

Finally, the Output column presents the results derived from the simulations and analysis. These outputs include energy consumption values for each design scenario, identification of optimal WWR and orientation combinations, improved daylighting potential, and design recommendations that balance thermal comfort and energy efficiency. These findings serve as evidence-based guidelines for improving urban residential building design, particularly in fast-growing towns like Lamahi, where such considerations are often overlooked.

3.5 Methods of Data collection

3.5.1 Sampling

In order to collect the field data for this research, a comprehensive questionnaire survey was conducted to analyze the energy consumption patterns of 14 households. This survey aimed to gather insights into the daily energy usage, seasonal variations, and the overall energy efficiency practices followed by these households. A specific focus was given to understanding the factors influencing energy consumption, such as household size, appliances used, and heating or cooling requirements.

A typical section of row housing in Lamahi town planning was selected for detailed

study, considering its representativeness in the broader context of urban housing in the region. The survey was also conducted within this selected housing section to collect more accurate and localized data. This area was chosen due to its relatively uniform construction style, household composition, and energy needs, which made it ideal for studying energy patterns and evaluating potential improvements in energy efficiency.

3.5.2 Operationalization

The detailed study and measurement of the selected houses were conducted to facilitate an in-depth understanding of their Window-to-Wall Ratio (WWR) and orientation, both of which play a crucial role in determining energy efficiency and natural lighting within the buildings. The assessment aimed to analyze how these architectural elements contribute to the overall energy consumption patterns observed in the surveyed households.

This involved preparing accurate building layouts, documenting architectural features, material usage, and construction techniques, as well as establishing baseline data for energy simulations. Detailed measurements of the building envelopes, including wall thickness, window placement, and shading devices, were also taken to understand their impact on thermal performance and ventilation. In addition, an evaluation of material properties, such as thermal conductivity, was conducted to identify how these factors influence heating and cooling loads.

The municipal guidelines and provisions for urban development and building construction were used for cross-validation of these features. These guidelines provided a regulatory framework that ensured the collected data was aligned with local standards and allowed for comparisons with best practices in energy-efficient building design. By integrating this regulatory perspective, the study also aimed to assess whether the selected buildings conformed to or deviated from established norms for energy-efficient design and construction.

3.5.3 Data Collection

The field data for this study were primarily collected through a structured questionnaire survey, aimed at understanding the energy consumption patterns of the households in the selected area. This quantitative approach allowed for the collection of data on various aspects of energy usage, such as electricity consumption, heating and cooling requirements, appliance usage, and the impact of household behaviors on overall energy

demand.

In addition to the questionnaire, unstructured interviews were conducted with local authorities and key informants, such as urban planners, architects, and building contractors. These interviews provided valuable qualitative data that helped to contextualize the quantitative findings, offering insights into local building practices, challenges faced in energy-efficient construction, and community awareness of energy-saving measures.

Weather data, which plays a critical role in understanding the climatic influence on energy consumption, was collected from the Department of Hydrology and Meteorology (DHM). This data provided crucial information about temperature variations, precipitation, and seasonal changes, which were used to model the thermal performance of buildings in the region. Additionally, data from the EnergyPlus database, a widely used tool for building energy simulations, was also utilized to further enhance the accuracy of the energy models and simulations.

To ensure that the study aligned with existing frameworks and policies, governmental policies and provisions related to residential building design were thoroughly studied. This included national and local guidelines on energy efficiency, sustainable construction practices, and building codes. By analyzing these regulations, the study aimed to provide well-informed recommendations that adhere to the guiding factors of residential building design, ensuring that proposed strategies are both feasible and compliant with current policies.

3.5.4 Data Analysis

The data collected from various sources were analyzed using both quantitative and qualitative methods to evaluate the energy performance, daylighting, and key factors affecting building orientation and Window-to-Wall Ratio (WWR) in Lamahi. The quantitative analysis focused on processing and interpreting energy consumption patterns, while the qualitative analysis examined the design aspects and contextual factors influencing the energy behavior of the buildings.

Data on energy consumption patterns collected from the 14 households in the case study area were processed and analyzed using MS Excel. This analysis involved organizing the data into relevant categories, identifying consumption trends, and calculating overall energy use per household. Statistical tools and graphical representations were

employed to identify patterns and correlations, such as peak usage times, seasonal variations, and differences in energy consumption across households with varying sizes and types of appliances.

In addition to the quantitative data, notes from on-site observations were reviewed to identify building design features, spatial arrangements, and material choices that impacted thermal comfort and energy performance. These observations focused on the configuration of walls, windows, and roofs, as well as the materials used, which influence both the thermal insulation properties and the overall energy efficiency of the buildings. The layout and orientation of the buildings were also documented to understand how these factors interact with local climate conditions to affect energy consumption.

These on-site observations helped contextualize the quantitative and qualitative findings, providing a richer understanding of residential building construction in the case study area. By combining these insights with the energy consumption data, a more comprehensive view of how the built environment affects energy performance emerged.

Energy simulation models were developed using Rhino software, incorporating the UMI (Urban Modeling Interface) tool to create accurate simulations of the buildings' energy performance. These models enabled a virtual representation of the buildings under different conditions. WWR and orientation were altered to create various scenarios, allowing for the evaluation of how changes in these parameters could impact energy consumption, thermal comfort, and daylighting. This iterative process helped identify optimal configurations for improving energy efficiency while maintaining adequate natural lighting levels inside the homes.

3.6 Methodological framework

Figure 8 presents a detailed flowchart of the research methodology employed in this study, outlining each phase systematically to ensure a comprehensive and structured approach to the investigation. The process is broadly divided into three key segments: the Preliminary Phase, Data Collection and Analysis, and Conclusion and Recommendation stages.

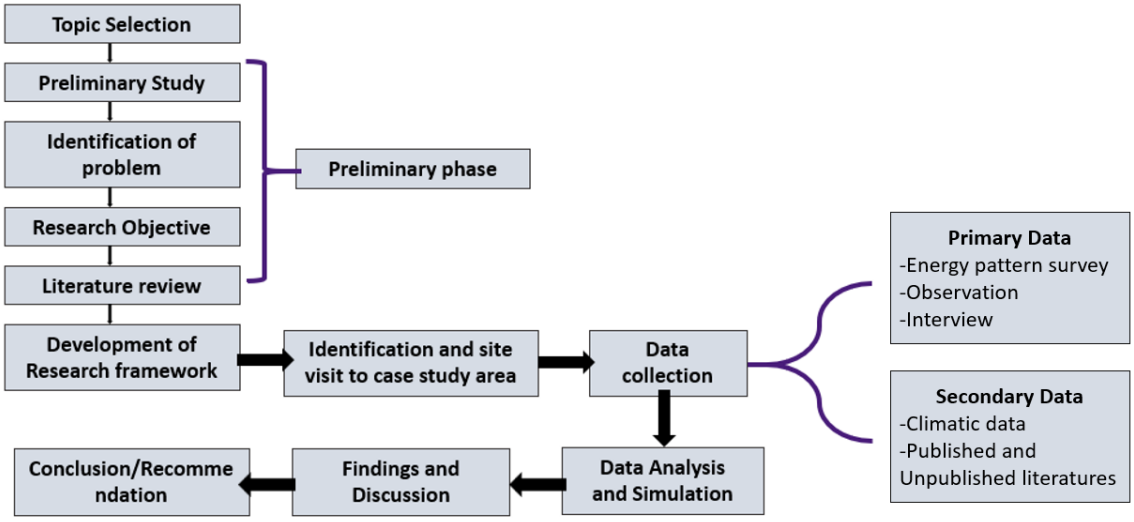

Figure 8 Methodological framework of the study

The Preliminary Phase forms the foundation of the research and involves several crucial steps that help in shaping the scope and direction of the study. It begins with the selection of a research topic, which is a critical step that sets the tone for the entire research process. This is followed by a preliminary study that involves an initial exploration of the topic to understand its relevance, scope, and the existing gaps in knowledge. Based on this, the next step is the identification of the research problem, which defines the core issue that the study aims to address. Once the problem is clearly outlined, the research objectives are formulated, guiding the study with specific goals to be achieved. A comprehensive literature review is then conducted to understand previous research in the area, identify knowledge gaps, and support the theoretical framework of the study. These steps collectively comprise the Preliminary Phase, as shown in the figure.

After completing the preliminary phase, the research progresses to the development of the research framework, which provides a structural plan for conducting the study. This is followed by the identification and site visit to the selected case study area, an essential step that grounds the research in a real-world context. The site visit enables the researcher to observe the actual conditions, interact with stakeholders, and refine the research tools based on the field setting.

The next step is data collection, which is a crucial part of the methodology. Data is gathered from both primary and secondary sources. Primary data includes responses and observations gathered directly from the field through energy pattern surveys,

interviews, and on-site observations. These methods help obtain first-hand information on energy usage, behavior, and socio-economic conditions. On the other hand, secondary data involves climatic data and relevant published or unpublished literature, which provide additional context, historical background, and comparative information necessary for in-depth analysis.

Following data collection, the study enters the Data Analysis and Simulation phase. In this stage, the collected data is processed, interpreted, and analyzed using relevant tools and techniques. Simulations may be carried out to predict outcomes, identify patterns, and test various scenarios. This analytical process forms the backbone of the research, transforming raw data into meaningful insights.

Based on the analysis, the Findings and Discussion section is developed, where results are critically examined in light of the research objectives and existing literature. This section helps to contextualize the findings, draw connections, and highlight key insights. The final step in the methodology is the Conclusion and Recommendation phase, where the main findings are summarized, and practical recommendations are provided. These may include policy suggestions, design guidelines, or proposals for future research.

CHAPTER 4: CASE STUDY AREA

4.1 Introduction

Lamahi Town Planning, located in Ratodada, Lamahi Municipality of Dang District in Lumbini Province, is a rapidly developing residential zone experiencing significant urban expansion. The area has emerged as a focal point for planned urban development, supported by increasing population growth, improved transportation networks, and infrastructure upgrades. Lamahi's strategic location along the East-West Highway (Mahendra Highway) has further boosted its connectivity, making it an attractive site for residential and commercial investment. The town has also witnessed substantial land development initiatives under land pooling schemes, aimed at promoting organized growth while preserving essential public spaces and road networks (DUDBC, 2015).

According to the 2021 Nepal Census, Dang District had a population of approximately 652,000, a substantial increase from previous decades, reflecting the growing migration toward urban centers like Lamahi (Central Bureau of Statistics [CBS], 2021). This demographic shift is primarily driven by rural-to-urban migration in search of better employment, education, healthcare, and living conditions. As a result, there has been a marked rise in housing demand, prompting increased construction activities and the proliferation of row housing developments, particularly in areas like Ratodada.

Lamahi Town Planning plays a pivotal role in shaping sustainable urban development in the region by implementing modern planning tools such as Geographic Information Systems (GIS), zoning regulations, and environmentally conscious urban design principles (MoUD, 2017). The integration of these tools facilitates efficient land use and infrastructure provision, contributing to the town's structured growth. Furthermore, the town's development aligns with the national vision of promoting secondary cities as alternative growth hubs to reduce pressure on the Kathmandu Valley (National Planning Commission, 2020).

With these efforts, Lamahi is gradually transforming into a well-organized urban center characterized by planned residential layouts, designated green spaces, and provision of urban amenities, reflecting broader trends in decentralized development and balanced regional growth across Nepal.

Figure 9 Lamahi town planning in 2010 AD (Source: Google earth)

One of the critical design aspects influencing energy efficiency in this region is the Window-to-Wall Ratio (WWR) and the solar orientation of buildings, both of which significantly affect the thermal performance, daylight penetration, and overall energy consumption of residential structures. In Ratodada, Lamahi, many of the newly constructed residential buildings display a wide range of WWR configurations, often without a consistent design standard or guideline. These variations directly influence the level of natural lighting, indoor air quality through ventilation, and the energy demand for space heating and cooling.

Research suggests that buildings oriented toward the south and designed with optimized WWR tend to perform better in terms of energy efficiency, particularly in climates similar to that of Dang, which experiences hot summers and mild winters. Such orientation takes advantage of passive solar heating during winter while minimizing direct solar gain during summer through the use of shading devices and properly sized openings. This passive solar design strategy reduces the load on mechanical heating and cooling systems, thereby cutting down on energy consumption and associated costs.

However, many buildings in the area are constructed without proper orientation analysis or simulation-based design, resulting in suboptimal thermal comfort and increased reliance on artificial heating and cooling systems. For instance, east- or west-facing windows with high WWR can lead to significant overheating during summer mornings and afternoons, while poorly insulated large windows on the north side can increase heat loss in winter. These issues are often exacerbated by the use of low-performance glazing and inadequate shading strategies.

As Ratodada continues to urbanize rapidly, the integration of climate-responsive design elements—particularly optimized WWR and strategic building orientation—will be vital in achieving energy-efficient and environmentally sustainable housing. Encouraging the adoption of performance-based building design, supported by tools such as building energy simulations and daylighting analysis, can ensure that future developments meet both thermal comfort and energy efficiency benchmarks (Wang et al., 2006). Urban development authorities and planning bodies should prioritize capacity-building and awareness programs to ensure architects, engineers, and builders understand the implications of WWR and orientation on building energy performance.

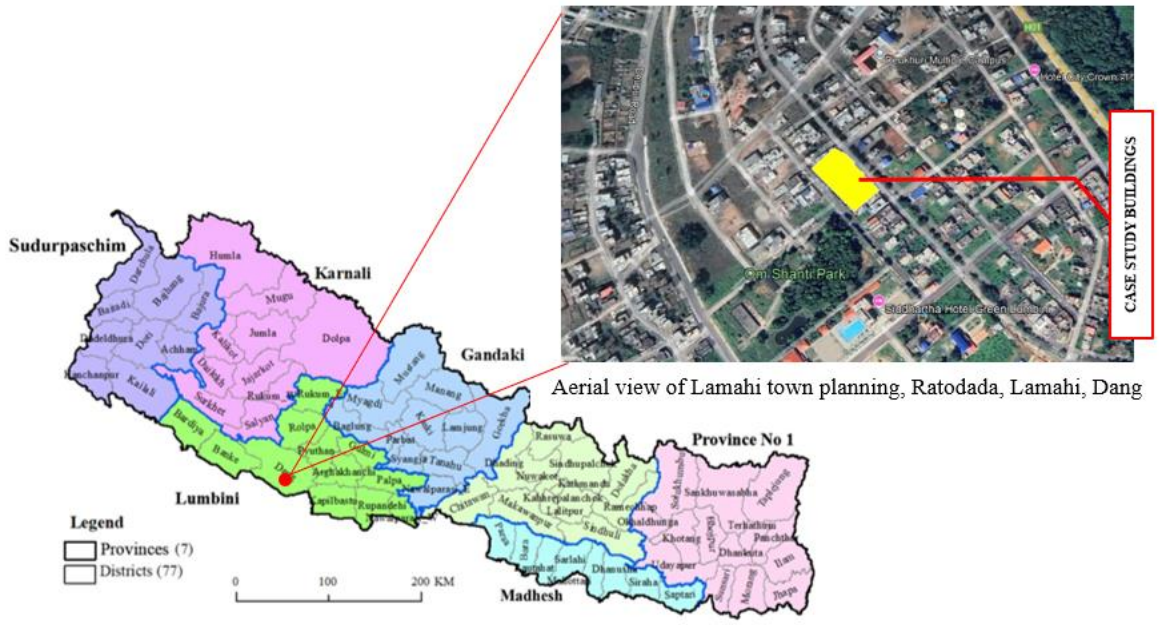

Figure 10 Location map of case study area

Figure 11 Aerial map of case study area with building orientation (Source: Google satellite)

The figure presents a satellite map of a selected neighborhood inside Lamahi Ratodada Town Planning, illustrating the orientation of individual buildings within the study area. Each building is marked with a colored circle indicating its alignment—red circles represent buildings oriented along the east–west axis, while green circles denote those aligned along the north–south axis. A clear legend on the right-hand side of the image explains this classification, and a north arrow is provided for directional reference.

The spatial distribution shown in the figure reveals that buildings in the southern and central zones of the area predominantly follow a north–south orientation, while those in the northern part of the settlement exhibit a higher concentration of east–west oriented structures. This mixed orientation pattern suggests a lack of uniform planning, possibly due to irregular plot shapes, access road alignments, or informal construction practices.

This map plays a crucial role in understanding how orientation affects building performance, particularly in terms of solar exposure, ventilation, and energy efficiency. The orientation of a building can significantly influence indoor thermal comfort and the potential for passive heating or cooling, making it an important parameter for energy-conscious urban design. In the context of this research, the figure supports the broader

analysis of how spatial planning and building orientation contribute to the energy behavior of settlements, especially in low-income or informally developed areas.

4.2 Climatic condition of Ratodada

The 10-year (2011–2021) climate data for the nearest meteorological station to the case area, i.e., Lamahi in Dang, was obtained from the Department of Hydrology and Meteorology, Government of Nepal, to analyze the climatic conditions. The data includes the average ambient temperature, relative humidity, and precipitation levels over this period. To assess seasonal variations, summer (May and June) and winter (January and February) data were analyzed separately. Lamahi lies in the Inner Terai region, characterized by a flat valley enclosed by surrounding hills, influencing local climatic conditions. The average ambient temperature during winter is recorded as 20.8°C during the day and 7.9°C at night. The relative humidity in the winter months (December–February) averages around 78%, while the total precipitation recorded is approximately 240 mm. Understanding these climatic parameters is crucial for designing energy-efficient residential buildings in Ratodada, particularly in optimizing window-to-wall ratios (WWR) and building orientation to enhance thermal comfort and reduce energy demand.

SN	Month	Tmax	Tmin	Tavg	Rh 9(am)	Rh 3(pm)	Avg Wind Speed (m/s)
1	Jan	21.9	4.7	11.8	74	67	1.06
2	Feb	25.3	4.2	15.1	69	56	1.59
3	Mar	28.1	6.2	18.5	57	42	1.37
4	Apr	33.4	11.1	23.3	45	32	1.68
5	May	34.5	16	25.7	53	47	1.81
6	Jun	35.8	19.9	26.3	74	67	0.99
7	Jul	31.9	21.6	25.8	86	80	0.94
8	Aug	30.6	22.2	25.5	84	80	1.39
9	Sep	30.2	21.6	24.9	85	82	1.21
10	Oct	32.4	14.6	21.4	74	66	0.88
11	Nov	27.4	10.9	16.7	82	71	1.18
12	Dec	23.1	5.7	12.4	75	61	0.9

Figure 12 Climate data of Dang district (Source: Energy plus)

Table 12 presents detailed monthly climatic data for a particular location throughout the year. It includes essential meteorological parameters such as maximum temperature (Tmax), minimum temperature (Tmin), average temperature (Tavg), relative humidity

at 9 AM and 3 PM (Rh 9am and Rh 3pm), and average wind speed in meters per second. This data is crucial for climate-responsive architectural design and energy efficiency analysis, especially in understanding seasonal variations that influence thermal comfort and building performance.

The temperature data reveals a clear seasonal trend. The average maximum temperature (Tmax) gradually increases from 21.9°C in January to a peak of 35.8°C in June, indicating the hottest period of the year. After June, Tmax begins to decline, reaching 23.1°C by December. Similarly, the average minimum temperature (Tmin) shows a steady rise from 4.2°C in February to 22.2°C in August, before gradually dropping again. The average temperature (Tavg) follows a similar pattern, starting at 11.8°C in January, peaking at 26.3°C in June, and then falling back to 12.4°C in December. These trends clearly indicate a hot summer season from April to August and cooler winter months from November to February.

Relative humidity (Rh) data is presented for two different times of the day—9 AM and 3 PM. Morning humidity (Rh 9am) is generally higher than in the afternoon and peaks during the monsoon months of July and August, reaching 84% and 86% respectively. Afternoon humidity (Rh 3pm) shows a similar seasonal pattern but with lower values, reaching the highest levels in August (80%) and the lowest in April (32%). This variation between morning and afternoon humidity highlights the diurnal moisture fluctuation typical of tropical and sub-tropical climates.

Wind speed data indicates relatively moderate air movement throughout the year. The average wind speed ranges from a low of 0.88 m/s in October to a high of 1.81 m/s in May. The higher wind speeds during April and May may offer potential for natural ventilation strategies, while the lower wind speeds during cooler months may contribute to reduced convective heat loss.

Since the weather stations are not installed in case study area, simulated weather can help to get idea on annual climatic conditions in the area. Meteoblue has provided simulated climate data for the case study area, Lahami (Fig11).

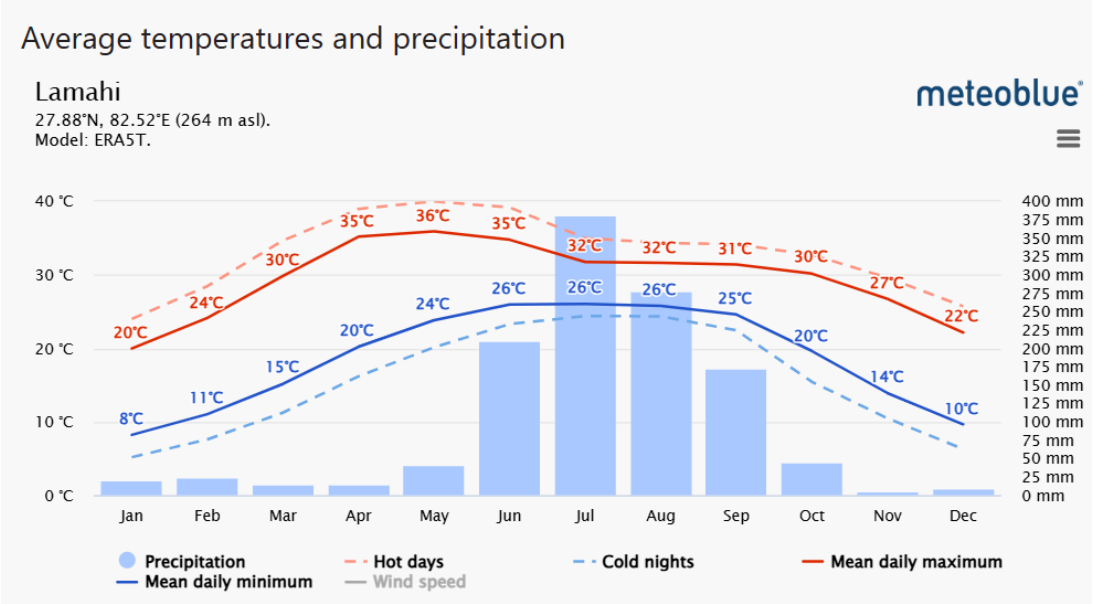

Figure 13 Climate data of Lamahi (Source: Meteoblue)

Figure 13 illustrates the average temperatures and precipitation trends for Lamahi, located at 27.88°N latitude and 82.52°E longitude, with an elevation of 264 meters above sea level. The climate data, modeled by ERA5T, show significant seasonal variations throughout the year.

Mean daily maximum temperatures (solid red line) begin at around 20°C in January, gradually rising to a peak of 36°C in May before declining to approximately 22°C in December. Meanwhile, mean daily minimum temperatures (solid blue line) follow a similar pattern, ranging from 8°C in January to about 26°C in July and August, then decreasing towards 10°C by December. The dashed red line indicates the frequency of hot days, peaking in May and June, while the dashed blue line represents cold nights, most common in January and December.

Precipitation (blue bars) is low during the winter and spring months but rises sharply starting in June, reaching its highest levels in July (around 375 mm), before tapering off in September and returning to minimal levels by November. This indicates a pronounced monsoon season from June to September. Overall, the climate of Lamahi is characterized by hot summers, mild winters, and a distinct wet season during the middle of the year.

4.3 Buildings in case study area

The buildings in the study area primarily range from two to four stories, with a mix of single-family and multi-unit dwellings. Most structures follow a north-south

orientation, aligning with the base case for daylighting and energy analysis. The window-to-wall ratio (WWR) is approximately 20%, though variations exist, especially in buildings with larger facade openings.

Figure 14 Buildings typologies in the study area

The houses shown in Figure 14 reflect typical urban and semi-urban construction styles found in places like Lamahi, Nepal. These buildings are primarily constructed using reinforced concrete (RCC) frames, which consist of concrete columns, beams, and slabs reinforced with steel bars. RCC is widely adopted in the region due to its durability and relative resistance to seismic activity when properly designed. The walls are typically infilled with burnt clay bricks or concrete blocks bonded with cement mortar, providing structural support and thermal insulation. These walls are then plastered with a cement-sand mix and finished with exterior-grade paint for both aesthetics and weather protection.

The roofs are flat and made of RCC slabs, a common feature in Nepalese homes, allowing them to be used for various purposes such as placing water tanks, solar panels, or drying clothes. Doors and windows are usually fabricated from metal—such as steel or aluminum—or occasionally from wood, depending on the homeowner's budget and preferences. Window designs often incorporate glass panes to allow natural light, and many buildings include iron grilles for added security. Overall, these materials and techniques represent a blend of local construction traditions with modern urban building practices.

CHAPTER 5: MODELLING AND SIMULATION

5.1 Approach to UMI

The Urban Modelling Interface (UMI) is an advanced simulation tool developed to evaluate various aspects of urban design, particularly building energy performance, daylighting potential, and overall urban sustainability, especially at a neighborhood or district scale. UMI is designed to work in integration with modeling platforms like Rhino and Grasshopper, which facilitates the creation of highly detailed and parametric urban models. This integration allows users to analyze complex urban environments while incorporating a wide range of environmental and energy-related metrics. The tool is particularly valuable for architects, urban planners, and researchers seeking to simulate and optimize building performance within a broader urban context.

In the context of this study, UMI was employed to explore the effects of building orientation and Window-to-Wall Ratio (WWR) on energy consumption patterns and daylighting efficiency in the selected case study area. The process began with the creation of accurate digital representations of buildings using Rhino, followed by the assignment of specific building parameters and energy profiles. These models were then simulated in UMI to assess heating, cooling, and artificial lighting demands. Multiple iterations were carried out, adjusting the orientation of buildings and varying the WWR to examine their influence on indoor thermal comfort and daylight penetration. Through these simulations, UMI enabled the identification of optimal configurations that strike a balance between minimizing energy use and maximizing natural light availability. The insights gained from this analysis were not only quantitative but also instrumental in supporting informed, data-driven decisions aimed at promoting energy-efficient and climate-responsive urban development.

5.2 Case study area

The case study area in Lamahi Town Planning, Ratodata, Lamahi was selected. In the case study area, a building zone consisting of 14 buildings in row housing model was selected for detailed study. The parameters like material properties, occupancy, occupant behavior, energy consumption per unit area, etc. was kept constant for case study building. These parameters were selected based on primary data from questionnaire survey, observation and secondary data such as municipal restrictions and guidelines.

5.2.1 Base case scenario

In this study, the base case scenario was established by considering the existing building orientation and Window-to-Wall Ratio (WWR) observed on-site. The orientation of the buildings in the base case followed a North–South alignment, arranged in a linear or row mode, which reflects the predominant layout of the structures in the study area. This orientation was selected as the default configuration to represent the current urban fabric without any alterations.

For the WWR, a value of 20% was adopted, which was determined through on-site measurements and observations of typical residential units. This value represents the ratio of window area to the total wall area of the building façades and serves as a crucial parameter in assessing both daylighting potential and energy performance. The base case was composed of a total of 14 houses, which were labeled sequentially from B1 to B14 for clarity and consistency throughout the analysis. These houses were digitally modeled with the above-mentioned parameters and used as a reference point for further simulations, allowing comparisons with alternative scenarios involving different orientations and WWR configurations.

Figure 15 Case study area in Ratodada, Lamahi

The materials used in construction of these houses were similar. All houses were RCC

structure buildings with 9” brick wall with plaster on both sides. The properties of the materials like U-value, thermal lag, admittance, solar absorption, weight, solar heat gain coefficient, visible transmittance, the refractive index of glass, etc are considered as provided by the software itself.

Table 2 U-value of materials use in the study

SN	Building Elements	Description	U-Value(w/m²K)
1	Plinth	150 mm sandstone soling+100 mm PCC+10 mm floor finish	2.78
2	Wall	110 mm brick and 10 mm plaster on either side	2.8
		230 mm Brick and 10 mm plaster on either side	1.9
3	Ceiling	Suspended concrete 110 mm and 10 mm plaster on either side and 5 mm floor finish	3.25
4	Roof	C.G.I.	5.62
5	Door	Solid Oak Timber	2.61
		30 mm Timbers with timber frame	3.11
6	Window	6 mm single pane of glass with timber frame	5.44

Table 2 provides a detailed breakdown of the thermal performance characteristics of various building envelope components, with a focus on their U-values, which indicate the rate of heat transfer through each element (measured in W/m²K). Lower U-values correspond to better insulation and reduced heat loss, making them critical in evaluating a building’s overall energy efficiency.

The plinth, which includes a 150 mm layer of sandstone soling, a 100 mm Plain Cement Concrete (PCC) layer, and a 10 mm floor finish, has a U-value of 2.78 W/m²K, reflecting a moderate level of thermal conductivity through the ground floor. The wall construction varies in type: one version features a 110 mm brick wall with 10 mm plaster on either side, resulting in a U-value of 2.8 W/m²K, while a thicker version, consisting of 230 mm of brick and the same plaster finish, has a lower U-value of 1.9 W/m²K, indicating improved thermal resistance due to increased mass.

The ceiling, composed of a 110 mm suspended concrete slab with 10 mm plaster on both sides and a 5 mm floor finish above, shows a U-value of 3.25 W/m²K, signifying relatively high heat transfer, likely due to the use of dense materials with minimal insulation. The roof, made from Corrugated Galvanized Iron (C.G.I.), has a significantly high U-value of 5.62 W/m²K, pointing to poor insulation and a high rate of heat gain or loss, which can critically affect indoor comfort, particularly in extreme weather conditions.

Regarding doors, two types are listed: one constructed from solid oak timber, with a U-value of 2.61 W/m²K, and another made from 30 mm timber panels within a timber frame, having a slightly higher U-value of 3.11 W/m²K, suggesting slightly lower thermal performance compared to solid oak. Finally, the windows, composed of a 6 mm single-pane glass set in a timber frame, exhibit the highest U-value of all elements at 5.44 W/m²K, which indicates substantial heat transfer and low insulating capability, typical of single glazing without thermal breaks.

There were slight variations in WWR, however we considered 20% WWR as an average value for base case model. Other parameters were kept constant for this study, however, help from field study, observation and questionnaire survey were taken into consideration while assigning those values.

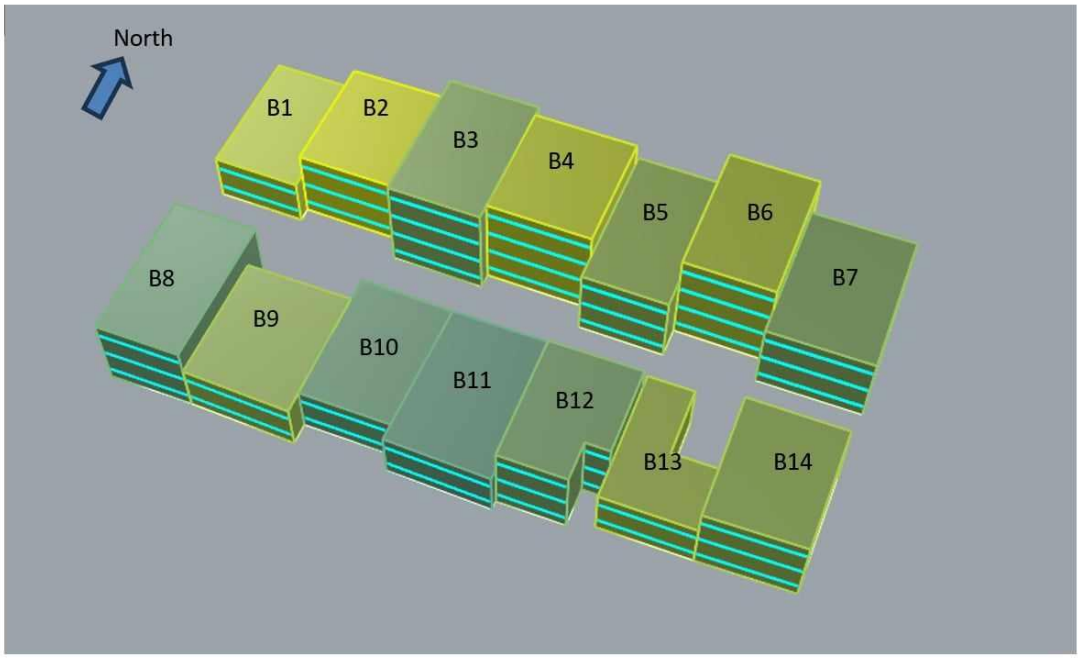

Figure 16 Row housing box model (base case) for simulation

Figure 16 illustrates the 3D representation of the building cluster used for the simulation. The model comprises fourteen distinct buildings, labeled B1 through B14. These buildings are arranged in two parallel rows, representing a hypothetical urban neighborhood or institutional complex. Each block is color-coded, possibly indicating variations in design parameters such as material properties, building typologies, or thermal characteristics. The design accounts for multi-story structures, as evidenced by the cyan-colored lines that demarcate individual floor levels within each building.

The north direction is clearly marked in the model, which is critical for accurate simulation of solar exposure, shading patterns, and passive heating or cooling potential. This orientation enables a realistic assessment of the building cluster's performance in relation to diurnal and seasonal solar movement.

The model was developed to capture urban morphological characteristics, such as building height, spacing, and density. These attributes play a significant role in determining the simulation outcomes, especially in terms of mutual shading, wind flow, and daylight penetration. The diversity in the building heights and configurations allows for a comprehensive analysis of how different design choices influence energy use intensity (EUI), daylight autonomy (DA), and carbon emissions.

5.2.2 Parameters for simulation

For this study, systematic variations in both building orientation and Window-to-Wall Ratio (WWR) were conducted in addition to the analysis of the base case scenario. The aim was to identify the optimal combination of these parameters that would enhance building energy performance and daylighting efficiency. The WWR was varied across a range from 10% to 60%, with incremental steps of 10%, resulting in six distinct WWR values being tested. At the same time, the building orientation was rotated from 0° to 180°, with each step increasing by 30°, yielding seven different orientation angles for analysis.

By combining these two variables, a total of 42 simulation iterations were performed using the Urban Modelling Interface (UMI). Each iteration involved creating a digital model of the case study buildings with a specific WWR and orientation setting. The resulting simulations allowed for a comparative assessment of energy consumption related to heating, cooling, and lighting demands. This comprehensive parametric analysis made it possible to evaluate how different configurations influenced building performance and led to the identification of the most energy-efficient and daylight-optimized design strategies.

Figure 17 illustrates the configuration of simulation parameters used in the Urban Modeling Interface (UMI) for zone-based energy and environmental performance analysis. The inputs are divided into three main categories: internal loads, ventilation and infiltration, and building envelope and shading. These parameters were carefully defined to replicate realistic residential conditions in the context of the case study area.

Subfigure (a) represents the load settings, which define internal heat gains due to occupancy, equipment, and lighting. An occupancy density of 0.025 people/m² was applied, reflecting a low-density residential scenario. The occupancy schedule, labeled Lamahi_Res_Y_Occ, was used to capture daily and seasonal variations in occupancy patterns. The equipment power density was set at 4 W/m², with usage governed by the schedule Lamahi_Res_Y_Plg, while lighting power density was fixed at 2 W/m² based on the Lamahi_Res_Y_Lgt availability schedule. A target illuminance of 100 lux was specified to represent minimum residential lighting requirements. Notably, the lighting control system was set to “Off,” indicating that no automated dimming system was simulated.

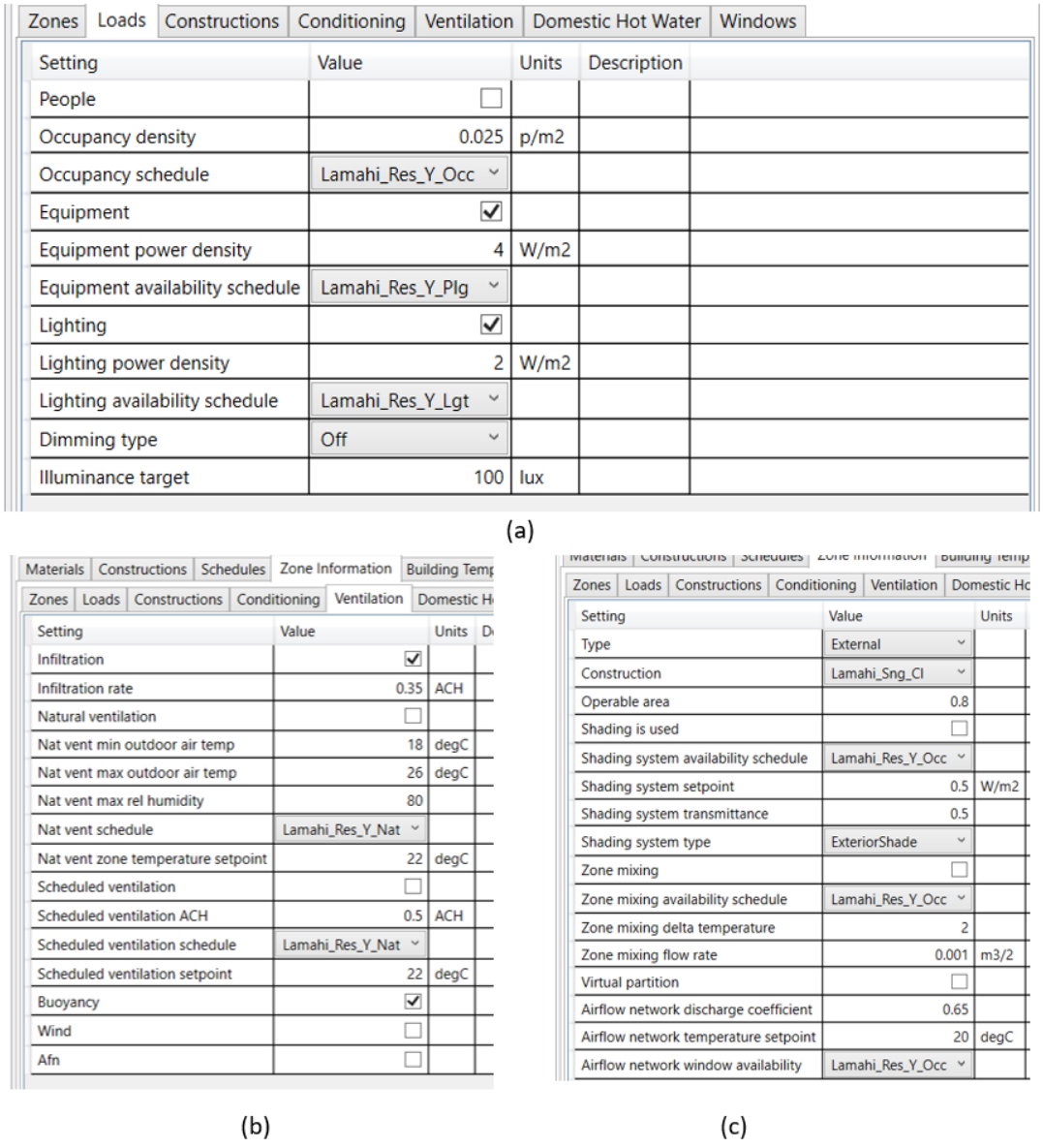

Figure 17 Parameters that were unchanged during simulation (a) Load, (b) Ventilation, and (c) fenestration materials

Subfigure (b) focuses on ventilation and infiltration parameters, which directly influence thermal comfort and energy demand for heating and cooling. The infiltration rate was defined as 0.35 air changes per hour (ACH), a standard value for moderately leaky residential buildings. Natural ventilation behavior was simulated based on temperature and humidity thresholds, with scheduling governed by Lamahi_Res_Y_Nat. Additional settings included the natural ventilation rate when the zone temperature exceeded setpoints, scheduled ventilation ACH (0.35), and associated temperature setpoints. These settings aim to replicate realistic passive ventilation behavior, enhancing indoor air quality while minimizing mechanical ventilation energy

use.

Subfigure (c) presents the envelope and shading system parameters. Windows were defined as external openings with operable areas that contribute to natural ventilation. The operability and shading availability were scheduled using Lamahi_Srg_O, while the shading system transmittance was set at 0.5, indicating moderate transparency. The system type was labeled ExteriorShade, reflecting external fixed or movable shading devices. Additional parameters, such as zone mixing availability, temperature setpoints for air mixing, and airflow network coefficients, were also included to simulate inter-zonal airflow and convective heat transfer. These detailed envelope and airflow inputs ensure accurate simulation of thermal exchange across building surfaces and between adjacent spaces.

CHAPTER 6: RESULTS AND DISCUSSION

6.1 Simulation of the row housing

6.1.1 Base case scenario

The base case scenario is modeled as an existing scenario, providing a realistic foundation for the analysis. All specifications are set as per the actual site conditions, taking into account the precise environmental, structural, and operational factors observed. This scenario is modeled in the best possible way to accurately represent the actual findings from the site. The layout, materials, and energy use are aligned with what is currently implemented, ensuring the model reflects real-world data as closely as possible.

As mentioned earlier in the literature review chapter, these base cases will be iterated to obtain an optimized model, with adjustments based on identified areas for improvement. The iterative process will involve refining key variables, such as energy consumption patterns, building materials, and system efficiencies. This optimization aims to strike a balance between energy efficiency and cost-effectiveness. The optimization process will focus on ensuring that the cumulative Daylight Autonomy (cDA) value falls within the range of 50-80%, as this is considered an ideal range for maximizing natural light while minimizing energy use from artificial lighting systems.

In the next stages of modeling, sensitivity analysis will be conducted to evaluate how different factors impact the performance of the model. Factors such as the type of insulation, window-to-wall ratio, and HVAC system configurations will be tested to identify the most effective combination for achieving the desired energy performance goals. The optimization procedure will also consider seasonal variations in climate and daylight availability to ensure the model remains efficient across different times of the year.

Building Name	cDa
B1	35
B2	40
B3	28
B4	37
B5	30
B6	34
B7	28
B8	25
B9	30
B10	24
B11	24
B12	26
B13	32
B14	30

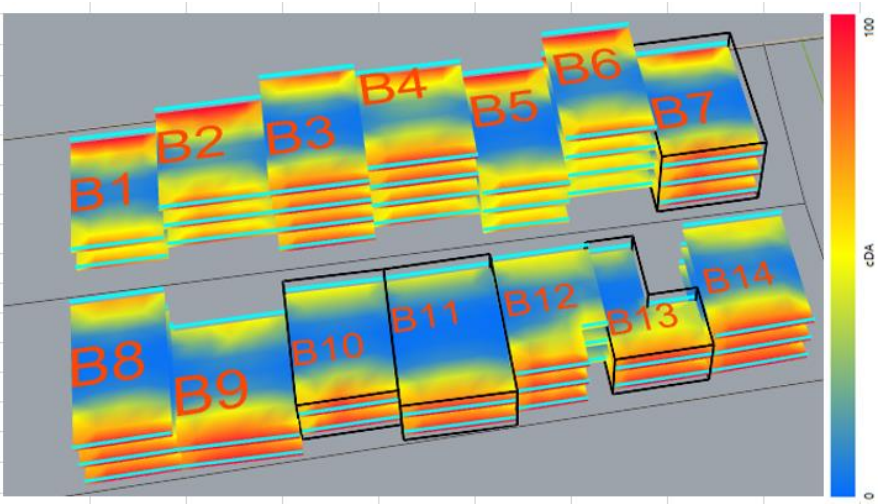

Figure 18 cDA values for buildings in base case scenario

This shows that at present there is issues with daylighting as well as lighting energy consumption. Only the areas that are near to openings get adequate light (300 lux), while all the other areas get inadequate light. ASHRAE 90.1 and the IES (Illuminating Engineering Society) Lighting Handbook recommends lux values of 300 for kitchen, study room, workstations, etc. It recommends lux values lower than 300 for bathrooms, staircase and living room. This means that at present condition, few spaces inside the houses are getting adequate lighting, however, the spaces where detailed observations are to be done requires additional lighting during day time. This reflects there is a possibility of optimization in orientation and WWR for energy efficiency in the case study area.

Table 3 Simulated monthly energy consumption for base case scenario

Building Name	Units	Jan	Feb	Mar	Apr	May	Jun	Jul
B1	kWh	111.35	100.58	111.35	107.76	111.35	107.76	111.35
B2	kWh	181.62	164.05	181.62	175.76	181.62	175.76	181.62
B3	kWh	254.36	229.75	254.36	246.16	254.36	246.16	254.36
B4	kWh	234.58	211.88	234.58	227.01	234.58	227.01	234.58
B5	kWh	181.75	164.16	181.75	175.89	181.75	175.89	181.75

B6	kWh	228.26	206.17	228.26	220.89	228.26	220.89	228.26
B7	kWh	208.55	188.37	208.55	201.82	208.55	201.82	208.55
B8	kWh	179.10	161.77	179.10	173.32	179.10	173.32	179.10
B9	kWh	129.05	116.57	129.05	124.89	129.05	124.89	129.05
B10	kWh	113.60	102.61	113.60	109.94	113.60	109.94	113.60
B11	kWh	141.71	128.00	141.71	137.14	141.71	137.14	141.71
B12	kWh	146.52	132.34	146.52	141.80	146.52	141.80	146.52
B13	kWh	81.89	73.96	81.89	79.24	81.89	79.24	81.89
B14	kWh	161.74	146.09	161.74	156.52	161.74	156.52	161.74

Building Name	Units	Aug	Sep	Oct	Nov	Dec	Total (Annual)
B1	kWh	111.35	107.76	111.35	107.76	111.35	1311.09
B2	kWh	181.62	175.76	181.62	175.76	181.62	2138.45
B3	kWh	254.36	246.16	254.36	246.16	254.36	2994.92
B4	kWh	234.58	227.01	234.58	227.01	234.58	2761.99
B5	kWh	181.75	175.89	181.75	175.89	181.75	2139.95
B6	kWh	228.26	220.89	228.26	220.89	228.26	2687.52
B7	kWh	208.55	201.82	208.55	201.82	208.55	2455.48
B8	kWh	179.10	173.32	179.10	173.32	179.10	2108.74

B9	kWh	129.05	124.89	129.05	124.89	129.05	1519.51
B10	kWh	113.60	109.94	113.60	109.94	113.60	1337.55
B11	kWh	141.71	137.14	141.71	137.14	141.71	1668.56
B12	kWh	146.52	141.80	146.52	141.80	146.52	1725.19
B13	kWh	81.89	79.24	81.89	79.24	81.89	964.14
B14	kWh	161.74	156.52	161.74	156.52	161.74	1904.33

Table 3 presents the monthly energy consumption (in kilowatt-hours, kWh) for 14 different buildings (B1 through B14) over a seven-month period, spanning from January to July. For each building, the energy consumption varies slightly from month to month, with some buildings showing relatively consistent values across the months, while others display more noticeable fluctuations.

For instance, Building B1 consistently uses 111.35 kWh in January, March, May, and July, while it drops slightly to 100.58 kWh in February and 107.76 kWh in April and June. Similar patterns of fluctuation are observed in other buildings, such as Building B2, which consumes 181.62 kWh in January, March, May, and July, with a slight decrease in February and April to 164.05 kWh and 175.76 kWh, respectively.

Some buildings, like B3, B6, and B9, show relatively stable consumption values with minor differences across the months. For example, Building B3 uses 254.36 kWh in January, March, May, and July, with small reductions in February and April to 229.75 kWh and 246.16 kWh, respectively. Meanwhile, other buildings, such as B4 and B5, also show similar trends with energy consumption decreasing slightly in the middle months before returning to a higher value in the later months.

In general, the energy consumption for each building is fairly consistent, with the variations from month to month likely reflecting seasonal changes or minor adjustments in energy use patterns. The data could be useful for identifying trends in energy consumption and for planning energy-saving measures tailored to each building's specific usage profile.

6.1.2 Iterations in simulations

For the case study row housing, 42 different combinations of WWR and orientation were simulated to find out the optimum combination. The WWR ranged from 10^{o} to 60^{o} at an interval of 10. Similarly, orientation varied from 0^{o} to 18^{o}, with an interval of 10^{o}. From these iterations, we achieved higher cDA values for higher WWR.

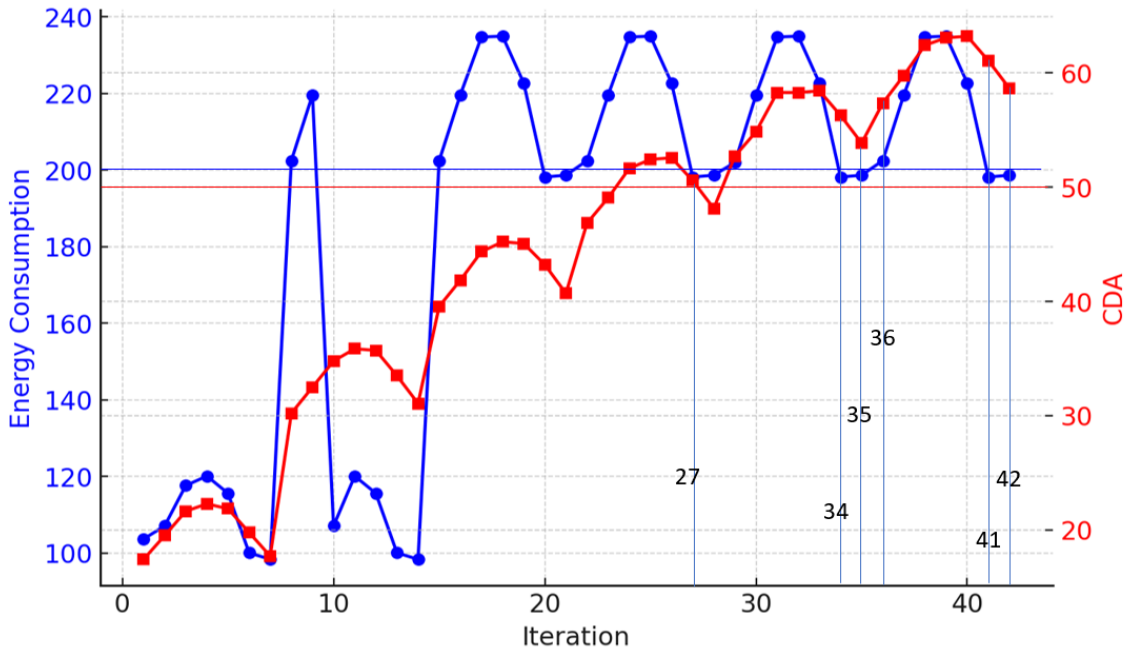

Figure 19 Relation between energy consumption and cDA with varying WWR and orientation

Figure 19 presents the optimization progress over multiple iterations, illustrating the trade-off relationship between Energy Consumption and CDA (Cumulative Daylight Autonomy) in the simulated design alternatives. The x-axis represents the number of iterations (ranging from 0 to 42), while the y-axes show two different performance metrics: energy consumption in blue (left axis, in kWh or similar units) and CDA in red (right axis, in percentage).

The blue curve, plotted with circular markers, represents the energy consumption values for each iteration. Initially, the energy consumption shows a general upward trend with sharp peaks and dips, reflecting significant variability as the optimization algorithm explores different design options. After iteration 20, the energy consumption begins to stabilize, oscillating around the 200-unit mark. This is emphasized by a horizontal blue line that represents a benchmark or target energy consumption threshold.

The red curve, marked with square data points, depicts the CDA values, which measure the percentage of interior space receiving adequate daylight over the year. Initially starting low (~10–20%), CDA values increase steadily across iterations, reaching over 60% by the final iterations. A red horizontal line is also plotted, likely denoting the target CDA threshold (around 50%), which is eventually surpassed and maintained after roughly iteration 30.

Several iterations—specifically 27, 34, 35, 36, 41, and 42—are annotated within the plot, suggesting that these may represent candidate solutions, possibly Pareto-optimal points, or design iterations chosen for further evaluation. These points appear where the energy consumption is either at a minimum or the CDA is maximized while staying within acceptable energy limits.

Table 4 Optimized values of WWR and Orientation

Iteration	WWR	Orientation	Energy consumption (kWh per year)	CDA
27	40	30	198.2	50.6
35	50	0	198.7	53.9
34	50	30	198.2	56.3
36	60	0	202.5	57.4
41	60	30	198.2	61.1
42	60	180	198.7	58.6

Table 4 presents the results of several design iterations, each varying in window-to-wall ratio (WWR), building orientation, annual energy consumption (kWh), and cumulative Daylight Autonomy (CDA). In Iteration 27, with a WWR of 40% and a 30° orientation, the building consumes 198.2 kWh annually, with a CDA of 50.6%. This represents a balanced design with moderate energy use and daylight availability. In Iteration 35, where the WWR is increased to 50% and the building is oriented at 0°, the energy consumption slightly rises to 198.7 kWh, but the CDA improves to 53.9%,

indicating better utilization of natural daylight. Iteration 34, with the same 50% WWR and a 30° orientation as Iteration 27, keeps the energy consumption at 198.2 kWh but increases the CDA to 56.3%, demonstrating improved daylight access without increasing energy use. Iteration 36 further increases the WWR to 60% and keeps the orientation at 0°, which leads to a slight rise in energy consumption to 202.5 kWh, while the CDA increases to 57.4%. This iteration suggests that larger windows improve daylight access, but with a slight increase in energy demand. In Iteration 41, with a 60% WWR and a 30° orientation, the energy consumption returns to 198.2 kWh, and the CDA increases to 61.1%, indicating a successful design that maximizes natural lighting while maintaining stable energy use. Finally, in Iteration 42, with a 60% WWR and a 180° orientation, the energy consumption is 198.7 kWh, and the CDA is 58.6%, showing a slight tradeoff between orientation and daylight performance. The variations for 90^{o} orientation are also the case of row housing blocks in the case study region-Lamahi town planning. Table 5 shows that for row housing that is facing east/west, the energy consumption is higher (18% above) as compared to existing base case.

Table 5 Variation in WWR for 90^{o} orientation

Iteration	WWR	Orientation	Energy consumption (kWh)	CDA
18	30	90	235	45.2
25	40	90	238	52.4
32	50	90	241	58.3
39	60	90	245	63.1

Table 5 illustrates the impact of varying window-to-wall ratio (WWR) on energy consumption and cumulative Daylight Autonomy (CDA) for a building with a fixed 90° orientation. As the WWR increases, there are noticeable changes in both energy use and daylight performance.

In Iteration 18, with a WWR of 30%, the building consumes 235 kWh of energy annually, and the CDA is 45.2%, indicating a relatively low level of natural light utilization and moderate energy consumption. When the WWR is increased to 40% in Iteration 25, the energy consumption rises slightly to 238 kWh, but the CDA improves significantly to 52.4%, reflecting better use of daylight within the building. In Iteration 32, with a 50% WWR, energy consumption increases further to 241 kWh, and the CDA rises to 58.3%, suggesting that larger windows lead to higher energy consumption but also allow for more daylight to penetrate the building. The trend continues in Iteration 39, where the WWR is 60%. Here, the energy consumption increases to 245 kWh, while the CDA reaches 63.1%, showing that larger windows provide more natural light but come at the cost of higher energy usage.

From the above ranges of combination with better performance, two combinations are selected as optimized combination for the case study area.

i. Optimized model 1 (50% WWR and no change in orientation)

ii. Optimized model 2 (40% WWR and 30^{o} orientation)

6.1.3 Optimized model 1

In this model, no change in orientation was made, however, WWR was kept at 50%. This ensures acceptable value of cDA while maintaining energy load on the building to an optimized value.

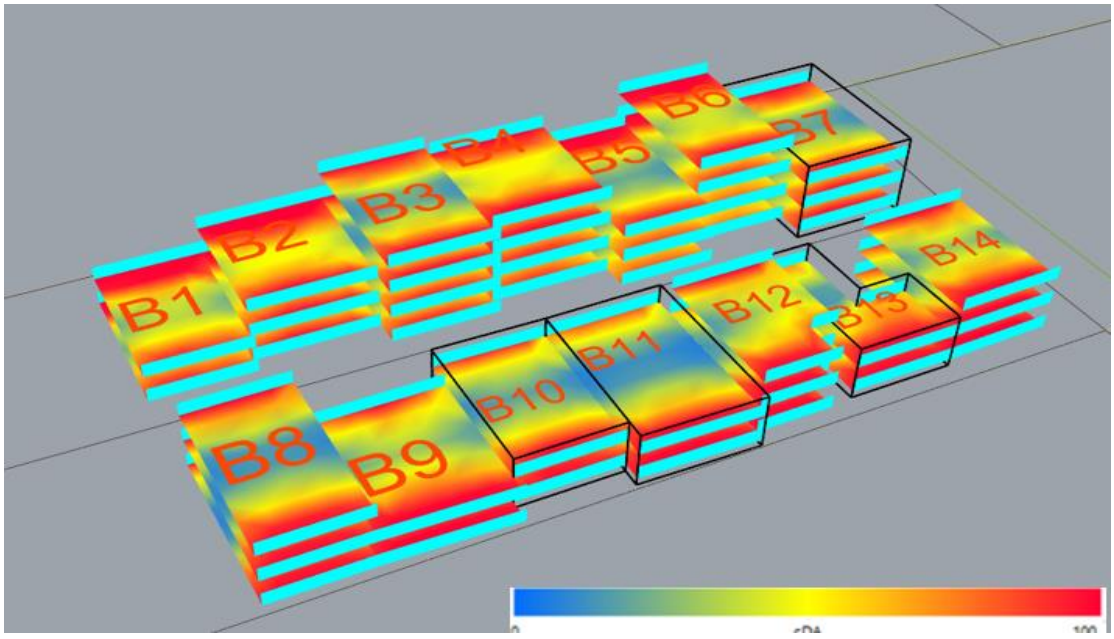

Figure 20 cDA for 50% WWR and no change in orientation

This figure showcases the optimized performance output generated using UMI (Urban Modeling Interface) while maintaining a Window Wall Ratio (WWR) of 50%. The visualization highlights various building zones, labeled as B1 to B14, with a color gradient representing the performance levels. Blue shades signify lower optimization values, whereas red indicates higher values, offering a clear visual comparison of zone performance.

Each zone's optimization is influenced by the chosen WWR, which is designed to strike a balance between natural daylight, energy efficiency, and thermal comfort. The 50% ratio ensures adequate daylight penetration without excessive heat gain or cooling loads, contributing to the overall efficiency of the building. Through this visualization, it becomes easier to identify which zones perform better under these design parameters.

6.1.4 Optimized model 2

In this model, a 30° orientation was chosen with a window-to-wall ratio (WWR) of 40%. This specific combination of orientation and WWR strikes a balance between maximizing natural daylight availability (cDA) and maintaining an optimized energy load on the building. The 30° orientation allows the building to capture sufficient daylight while avoiding excessive heat gain or loss, and the 40% WWR is considered a suitable window area to ensure adequate daylighting without significantly increasing energy consumption. This configuration ensures that the cDA value remains within an acceptable range, optimizing energy efficiency while still meeting the desired lighting levels. The combination ultimately allows the building to achieve energy-efficient performance without compromising occupant comfort or lighting needs.

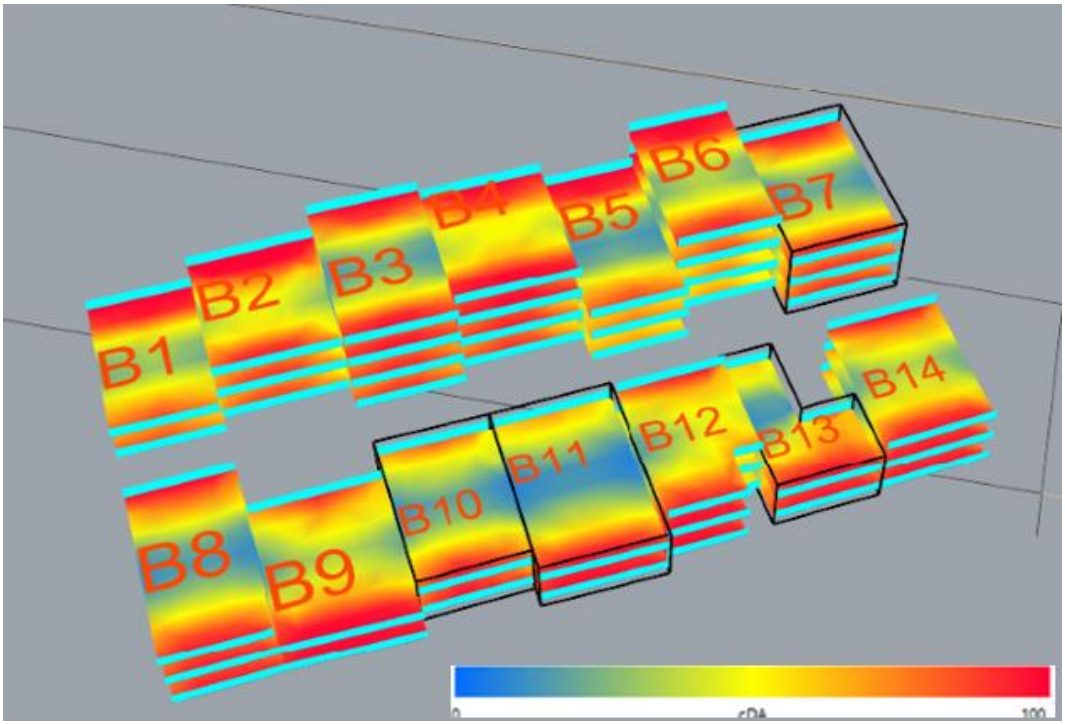

Figure 21 cDA for 40% WWR and 30º change in orientation

6.1.5 Unfavorable case

In the case study, certain combinations of window-to-wall ratio (WWR) and orientations have shown suboptimal performance. As depicted in Fig. 14, iterations 1-23 underperform in terms of cumulative Daylight Autonomy (cDA), while energy consumption fluctuates without a clear pattern. These iterations involve all configurations with a WWR of less than 40%, indicating that smaller window areas tend to limit natural daylight penetration, leading to lower cDA values and varying energy consumption.

On the other hand, iterations 31, 32, 38, 39, and 40 exhibit strong performance in terms of cDA, but their energy consumption is relatively high. These iterations involve WWRs of 50% and 60%, with building orientations of 60° and 90°. These orientations correspond to buildings facing eastwards or westwards, respectively. While these configurations improve daylight autonomy, the increased window area combined with eastward or westward orientations leads to greater solar heat gain or loss, resulting in higher energy usage. This highlights a tradeoff between maximizing daylight access and managing energy consumption, suggesting that while larger windows and certain orientations can improve natural lighting, they may require additional energy for temperature regulation.

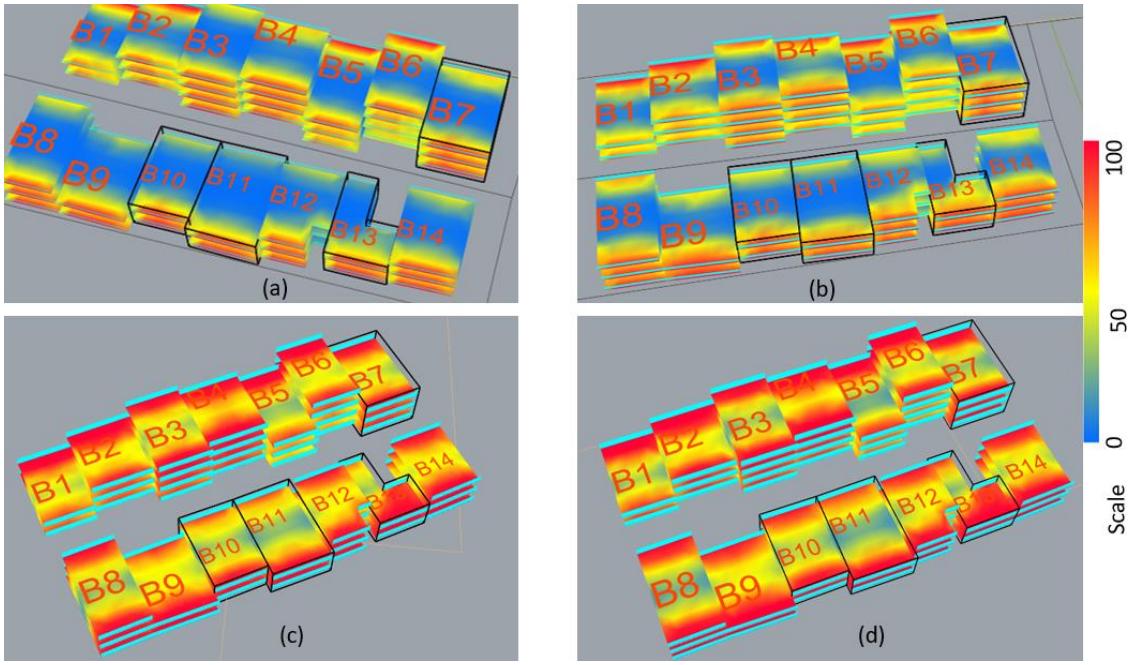

Figure 22 cDA for different WWR (a) 10%, (b) 20%, (c) 50% and (d) 60%

Figure 22 illustrates the climate-based Daylight Autonomy (cDA) analysis for different Window-to-Wall Ratios (WWR) — specifically 10%, 20%, 50%, and 60% — for a row of residential buildings (B1 to B14) within the modeled urban block. The simulation results, visualized using a color gradient from blue (0%) to red (100%), represent the percentage of occupied hours per year when interior spaces receive sufficient daylight (typically above 300 lux) without requiring artificial lighting.

In subfigure (a), which represents a WWR of 10%, most buildings exhibit predominantly blue and green tones, indicating poor daylight autonomy due to limited window openings. This suggests a high dependency on artificial lighting throughout the year. Subfigure (b), corresponding to a WWR of 20%, shows slight improvements, with some yellow and green regions beginning to appear, particularly on the roofs and facades facing favorable solar orientations. However, daylight penetration remains inadequate in many zones.

Subfigure (c), with a WWR of 50%, displays a significantly enhanced daylighting condition across the buildings, with more widespread yellow, orange, and red areas. This indicates that a 50% WWR achieves a well-balanced distribution of natural daylight, maximizing indoor lighting quality while minimizing glare and excessive solar heat gain. Lastly, subfigure (d), with a WWR of 60%, shows further increase in daylight autonomy, reflected by larger red-orange zones. While this suggests improved

daylight availability, it may also lead to potential overheating or visual discomfort due to excessive solar exposure.

6.2 Findings of the study

6.2.1. Impact of Window-to-Wall Ratio (WWR) on CDA

The findings of the study reveal a clear and consistent relationship between the Window-to-Wall Ratio (WWR) and CDA values. As the WWR increases from 10% to 60%, the CDA values also increase, suggesting that larger window areas allow for greater daylight penetration into the building, thereby improving Climate Daylight Autonomy. This trend is observed across all buildings and orientations. For example, Building B1, with a WWR of 10% and a 90° orientation, has a CDA of 23, while at a WWR of 60%, the CDA increases significantly to 64. The increase in CDA with higher WWR indicates that, all else being equal, larger windows lead to more natural light and a better ability to meet daylighting requirements without reliance on artificial lighting.

6.2.2. The Role of Orientation in Daylight Availability

Another key finding of the study is the significant role that orientation plays in determining the CDA values for the buildings. The study finds that buildings oriented between 60° and 120° (east to south-east/south) consistently show higher CDA values, indicating that these orientations are more favorable for daylight access. This trend can be attributed to the fact that these orientations receive more sunlight throughout the day, particularly in temperate climates where the sun is typically in the southern half of the sky. On the other hand, buildings oriented at 0° (north) and 180° (west) typically exhibit lower CDA values. For instance, Building B4, with a WWR of 30%, shows a CDA of 48 at 0° (north), 55 at 90° (south), and 49 at 180° (west), which clearly indicates that south-facing orientations receive the most consistent and abundant daylight. Therefore, the orientation of the building plays a critical role in maximizing natural lighting and minimizing the need for artificial lighting.

6.2.3 Optimal Orientation for Maximizing Daylight

The findings also highlight that the optimal orientation for maximizing daylight availability appears to fall within the range of 60° to 120°, with 90° (south) emerging as the most advantageous. Buildings facing this direction generally achieve the highest CDA values, as they receive a substantial amount of sunlight throughout the day, especially in the winter months when sunlight is lower in the sky. For example,

Building B13, with a WWR of 40%, shows a CDA of 57 at 90° (south) and 58 at 120° (south-east). This trend is observed across multiple buildings, suggesting that orienting glazed facades towards these orientations is an effective strategy for maximizing daylight availability. Such orientations reduce reliance on artificial lighting and can contribute significantly to energy efficiency in residential buildings.

6.2.4 Variation in Daylight Performance Across Different Buildings

While the general trends related to WWR and orientation hold true across most buildings, the findings also demonstrate that absolute CDA values vary significantly among the buildings. Buildings like B2, B4, and B13 consistently show higher CDA values across all WWR levels and orientations. These buildings are likely designed in a way that maximizes daylight access, such as larger floor plans, fewer obstructions, or better external conditions. In contrast, buildings such as B10, B11, and B8 exhibit lower CDA values, which could be due to factors such as building geometry, internal shading, or surrounding obstructions that limit daylight access. For example, at WWR 60% and 90° orientation, B2 achieves a CDA of 74, whereas B10 only reaches a CDA of 54. This variation emphasizes that building-specific factors, beyond WWR and orientation, significantly influence the daylight performance, and therefore, daylighting strategies must be tailored to each building.

6.2.5 Diminishing Returns with Higher WWR

The findings further indicate a diminishing return in CDA as the WWR increases beyond 50%. While the CDA values continue to rise with increasing WWR, the rate of increase slows down at higher WWR levels, particularly between 50% and 60%. This suggests that, while larger windows bring more daylight into the building, the additional benefit of increasing WWR beyond 50% is relatively small, and may not justify the increased energy demand or cooling load associated with larger glazing areas. For example, in Building B5, at a 90° orientation, the CDA value increases from 52 at WWR 50% to only 56 at WWR 60%. This suggests that after a certain threshold, further increases in glazing area do not result in proportional gains in daylight and may lead to other design challenges such as overheating, glare, and excessive cooling loads.

6.2.6 Design Implications for Optimal Daylighting

The study’s findings underscore the importance of carefully considering both orientation and WWR in the design of energy-efficient buildings that prioritize natural

lighting. To maximize daylight access, it is recommended to orient the primary glazed facades between 60° and 120° (east to south-east/south). These orientations are the most effective in ensuring consistent daylight penetration throughout the day and throughout the year. Additionally, the study suggests that WWRs between 30% and 50% strike the best balance between daylight availability and energy performance, offering significant daylight benefits without the risk of excessive heat gain or glare. Exceeding a WWR of 50%, especially up to 60%, may offer diminishing returns in daylight improvement and could lead to higher energy demands, requiring additional measures such as shading, glare control, or high-performance glass to mitigate potential issues like overheating and excessive cooling costs.

Overall, the findings of the study emphasize the critical role of building orientation and window-to-wall ratio (WWR) in achieving optimal daylight performance in residential buildings. Proper orientation of the building's glazed facades to the south or south-east/south-west maximizes natural light penetration, while a balanced WWR between 30% and 50% ensures adequate daylight availability without compromising thermal comfort or increasing energy demands. These findings provide valuable insights for designing energy-efficient buildings in temperate climates, particularly in areas like Lamahi, where natural lighting and thermal comfort are key factors in sustainable residential design.

CHAPTER 7: CONCLUSION

This study focused on examining the influence of building orientation and window-to-wall ratio (WWR) on the energy efficiency of residential buildings in Ratodada Town Planning, Lamahi, Dang. The research highlighted how variations in these design parameters could significantly impact energy consumption and daylight availability within the buildings. The findings concluded that optimizing the WWR and orientation could effectively reduce energy consumption by maximizing natural daylight and minimizing reliance on artificial lighting and heating. Properly balancing these factors is crucial for ensuring that buildings remain energy-efficient while still providing sufficient daylight to enhance occupant comfort. The study's insights contribute to the development of more sustainable building designs that prioritize both energy savings and the well-being of residents.

7.1 Key Findings

The findings from the study reveal that building orientation and window-to-wall ratio (WWR) play a crucial role in shaping the heating and cooling loads of residential buildings, which directly impacts their overall energy efficiency. These two design factors were found to significantly affect the amount of natural light that enters the building and how much energy is required to maintain thermal comfort. Based on the data collected, two optimized models were identified that strike an effective balance between minimizing energy consumption and maximizing daylight availability.

Optimized Model 1: WWR of 50% with 0° Orientation

Optimized Model 1 features a WWR of 50% and maintains the building's orientation at 0° (north). This configuration results in a monthly average energy consumption of 198.7 kWh and a cumulative Daylight Autonomy (cDA) of 53.9%. The 50% WWR allows for a significant amount of natural light to penetrate the building, thereby reducing the need for artificial lighting during the day. At the same time, the energy demand is kept relatively low due to the lack of direct exposure to the sun, which minimizes the cooling loads. This configuration serves as a well-balanced solution, as it ensures that energy consumption is optimized while still allowing sufficient daylight to enter the space, enhancing the thermal comfort for occupants.

Optimized Model 2: WWR of 40% with 30° Orientation Shift

Optimized Model 2, on the other hand, uses a WWR of 40% but incorporates a 30° shift

in orientation. In this model, the building's orientation is adjusted to 30° from true north, resulting in a slightly lower monthly energy consumption of 198.2 kWh and a cDA of 50.6%. The 30° adjustment in orientation reduces the building's exposure to the sun at peak hours, thereby decreasing the direct solar heat gains that contribute to increased cooling demands. This configuration represents a trade-off, as it slightly sacrifices daylight penetration in order to achieve a more efficient thermal performance. Nonetheless, it still provides a sufficient amount of natural light and significantly improves the building's cooling efficiency, making it another effective option for achieving energy optimization.

Inefficient Configurations

While both of the optimized models were successful in balancing energy consumption and daylight penetration, the study also highlighted certain building configurations that were inefficient. Specifically, buildings with a WWR below 40% were found to have insufficient daylight penetration. This led to an increased reliance on artificial lighting during the day, which, in turn, raised the building's overall energy demand. Insufficient daylight not only results in higher energy consumption but also diminishes the overall comfort and well-being of the occupants.

On the other hand, buildings with WWRs exceeding 50% presented challenges due to excessive solar heat gains. While a larger window area increases daylight availability, it also increases the amount of solar radiation that enters the building, leading to higher cooling energy requirements. This excess heat gain during warmer months can be detrimental to energy efficiency, as it forces the building's cooling system to work harder to maintain comfortable indoor temperatures.

Orientation-Related Findings

In terms of orientation, the study found that buildings with orientations of 60° or 90° (east or west) consistently exhibited higher energy consumption due to greater exposure to direct solar radiation during peak hours. During the summer, the east and west-facing orientations experience intense solar heat gain in the morning and late afternoon, respectively. This exposure increases the cooling load, which can lead to a higher overall energy demand for air conditioning.

Conversely, south-facing orientations (approximately 90°) were found to optimize both daylight penetration and energy efficiency. South-facing orientations are typically

better positioned to capture natural light throughout the day, without suffering from the extreme temperature fluctuations associated with other orientations. This results in the best overall thermal comfort and daylight availability, contributing to more efficient energy use. North-facing buildings (0°) tend to receive less solar heat, which reduces the cooling load but also limits the natural light available for the interior spaces, making it less ideal for maximizing daylight autonomy.

Impact of WWR and Orientation on Daylight and Energy Efficiency

The study also underscores the significant influence of WWR and orientation on the Climate Daylight Autonomy (CDA) values for each building. As the WWR increases, there is a corresponding increase in the CDA values, indicating that buildings with larger window areas generally provide better daylight availability. Higher WWRs, up to 50%, are ideal for maximizing daylight penetration while maintaining reasonable cooling loads. However, as the WWR exceeds 50%, the benefits of increased daylight are counterbalanced by the higher solar heat gains, which contribute to a higher cooling demand.

On the other hand, optimal orientations play a crucial role in ensuring the building receives sufficient daylight while minimizing excessive heat gain. Orientations that fall within the 60° to 120° range (east to south) tend to provide the highest CDA values, making them the most suitable for achieving optimal energy efficiency. These orientations balance the need for natural light while minimizing exposure to intense solar radiation.

In contrast, orientations at 0° (north) and 180° (west) generally show lower CDA values, indicating insufficient daylight availability. Buildings oriented to the north receive limited daylight, while west-facing buildings experience excessive solar heat gain in the late afternoon, leading to higher cooling demands and lower overall energy efficiency.

The study clearly demonstrates that both window-to-wall ratio (WWR) and building orientation have a substantial impact on the energy performance and thermal comfort of residential buildings. The findings emphasize the importance of finding an optimal balance between natural lighting and solar heat gain to achieve energy-efficient designs that maintain occupant comfort. Specifically, balancing WWR and orientations can effectively reduce energy consumption, optimize daylight availability, and enhance

overall building performance. These findings are critical for guiding the design of energy-efficient residential buildings, where both daylight quality and thermal comfort are prioritized for optimal living conditions.

7.2 Justification of Objective

This study has successfully answered and justified the objectives of this research, which is explained below.

7.2.1 Evaluate the impact of varying WWR on daylight access, and energy consumption

One of the core objectives of this study was to evaluate the impact of varying Window-to-Wall Ratios (WWR) on daylight access and energy consumption in the residential buildings of the Lamahi land pooling area. This objective was addressed through a series of daylight simulations using the Urban Modeling Interface (UMI), where four different WWR configurations—10%, 20%, 50%, and 60%—were analyzed across 14 residential buildings (B1 to B14).

The analysis of climate-based Daylight Autonomy (cDA) demonstrated a clear correlation between increasing WWR and improved daylight access. At 10% WWR, daylight penetration was minimal, as indicated by predominant blue and green zones in the simulation outputs (Figure 22a), signifying heavy reliance on artificial lighting. With an increase to 20% WWR, moderate improvement in daylight levels was observed, particularly on the upper floors and south-facing facades (Figure 22b). A significant improvement was noted at 50% WWR (Figure 22c), where a balanced distribution of daylight was achieved, characterized by widespread yellow and red zones indicating higher cDA values. The 60% WWR scenario (Figure 22d) further increased daylight levels; however, the potential for glare and overheating became more prominent, particularly on west-facing facades and roof surfaces.

Buildings such as B4 and B12 show significant increases in daylight contribution as WWR increases. B4 shows values rising from 22–28% at 10% WWR to 38–44% at 20% WWR. B12 improves from 18–22% to 31–36% over the same increase in WWR. These results confirm that higher WWR allows more daylight penetration, especially in orientations such as 60° to 120°, which are typically more favorable for solar access in temperate climates like Lamahi.

In addition to daylight performance, the energy implications of varying WWR were also considered. While higher WWRs contributed to increased daylight autonomy and potential reductions in artificial lighting demand, they also introduced risks of increased solar heat gain, which could elevate cooling energy loads. The 50% WWR scenario emerged as an optimal balance, offering improved natural lighting conditions while minimizing excessive thermal loads, making it the most energy-efficient configuration among those studied.

Through this analysis, the thesis successfully fulfilled the objective by quantifying the relationship between WWR and both daylight and energy performance. The findings support the integration of passive design strategies, such as optimized glazing ratios, in future land pooling developments to enhance energy efficiency and occupant comfort.

7.2.2 Assess the effect of different orientations on daylight and energy consumption

Another key objective of this study was to assess the effect of different building orientations on daylight access and associated energy consumption. This objective has been effectively addressed through a comprehensive orientation analysis using UMI simulations combined with orientation-specific Window-to-Wall Ratio (WWR) data for fourteen residential buildings in the Lamahi land pooling area.

The orientation analysis involved simulating daylight autonomy and solar radiation exposure at seven orientation angles: 0°, 30°, 60°, 90°, 120°, 150°, and 180°, for each building under varying WWR configurations. The data demonstrates that orientation has a significant impact on both daylight access and potential energy demand.

For instance, across multiple buildings (e.g., B1, B2, B4), daylight performance tends to peak between 60° and 120° orientations. For Building B4, the daylight contribution increases from 21% at 0° to 28% at 90° under a 10% WWR, and similarly rises to 44% at 90° under a 20% WWR. This indicates that east-southeast and south-facing orientations provide more favorable solar exposure throughout the day, enhancing daylight autonomy and reducing the need for artificial lighting during occupied hours.

However, energy performance is also influenced by orientation-specific solar gain. West-facing (150°–180°) orientations showed a decline in daylight autonomy compared to optimal southern exposures and are more susceptible to overheating,

which may increase cooling loads. For example, B12 and B14 show a gradual drop in daylight contribution from 90° toward 180°, implying reduced lighting efficiency and potentially higher thermal load.

The orientation-wise variation also helps to identify critical trade-offs. While 90° and 120° orientations provided higher daylight access, orientations such as 0° or 180°—especially when combined with large WWRs—risk increased solar heat gain without proportional daylight benefits. This relationship was further validated in simulation outputs (e.g., Figure 22), where daylight autonomy maps at different orientations clearly illustrated a spatial shift in daylight availability across façades as orientation changed.

Through these analyses, the thesis demonstrates that building orientation, when strategically planned, can significantly enhance natural lighting and reduce overall energy consumption. The findings emphasize the need to align building façades—particularly in land pooling developments—with solar-optimal orientations (i.e., between 60°–120°) to ensure passive solar gain for winter heating and daylighting while minimizing summer overheating.

In conclusion, the study successfully meets this objective by quantifying how orientation affects daylight availability and energy use. The insights gained support the integration of orientation-aware design practices in residential planning, ensuring energy-efficient development strategies in Nepalese urban housing projects.

7.2.3 Identify optimal orientation and WWR configurations to enhance energy efficiency in residential buildings

The third major objective of this research was to identify the optimal combinations of building orientation and Window-to-Wall Ratio (WWR) that would enhance energy efficiency in the residential buildings of the Lamahi land pooling area. This objective was achieved through a detailed simulation-based performance analysis using the Urban Modeling Interface (UMI), which assessed the daylight autonomy and energy implications of varying WWRs (10% to 60%) across seven orientations (0° to 180° in 30° increments).

The results of the simulations revealed two primary configurations that yielded the most favorable outcomes in terms of daylight access and energy performance:

1. 40% WWR at 30° Orientation:

   This configuration provided optimal daylight autonomy while minimizing excessive solar gains and overheating, particularly during summer months. Simulation results showed that at 30°, the solar incidence on façades was well-balanced, offering high daylight availability throughout the day without significant glare or overheating risks. Energy modeling under this setup reflected a reduction in artificial lighting demand while maintaining acceptable thermal comfort levels, making it a viable solution for new design orientations within planned developments.

2. 50% WWR at Existing Orientation:

   Considering the actual orientation of buildings within the Lamahi layout, simulations with a 50% WWR demonstrated a strong balance between visual comfort and energy efficiency. While higher than the 40% WWR scenario, the 50% WWR allowed for improved daylight penetration in existing site conditions, reducing dependency on artificial lighting during the daytime. Though it introduced slightly higher solar gains, the results indicated that this could still be managed effectively with passive shading strategies, thus maintaining energy efficiency within acceptable limits.

By comparing simulation outcomes across all scenarios, it was determined that while 40% WWR at 30° orientation is the most ideal from a design perspective, the 50% WWR at existing orientation is the most practical and efficient under current built conditions. These two configurations offer guidance for both future residential planning (in terms of block and plot orientation) and retrofitting strategies for existing layouts.

Therefore, this study successfully meets the objective by identifying two clear strategies—one optimized for design adaptability and another for existing feasibility—to improve energy performance in residential buildings. The results offer actionable recommendations for enhancing daylight use and reducing energy loads in similar urban housing developments across Nepal.

7.3 Implications and Recommendations

To implement energy-efficient building strategies, the following stakeholder-specific recommendations are offered:

- **Architects & Engineers**: It is recommended that architects and engineers adopt

window-to-wall ratio (WWR) values between 40% and 50%, with an orientation of either 0° or 30°. These configurations have been shown to optimize energy efficiency while maintaining adequate daylight penetration. Additionally, the integration of shading devices should be considered where necessary to control solar heat gain, ensuring that buildings remain comfortable without relying heavily on cooling systems.

- **Town Developers & Planners**: Developers and urban planners should design residential layouts that prioritize optimal building orientation, ensuring streets and plots are aligned for efficient solar exposure. This design approach would allow buildings to benefit from natural light and passive heating. Enforcing zoning regulations that mandate energy-efficient building designs can ensure that new developments contribute to the overall reduction in energy demand across the community.
- **Landowners & Homeowners**: Landowners and homeowners are encouraged to choose home designs that incorporate passive solar strategies, such as optimized window sizes and building orientations. Investing in energy-efficient glazing and high-quality insulation will also help reduce heating and cooling loads, further improving the energy efficiency of their homes and reducing long-term energy costs.
- **Government Authorities & Policymakers**: Governments and policymakers should introduce building regulations that standardize WWR and orientation guidelines, providing clear standards for energy-efficient building design. Financial incentives, such as tax breaks or subsidies, could be offered to homeowners and developers who incorporate energy-efficient features into their buildings, encouraging broader adoption of sustainable practices.
- **Researchers & Academicians**: Further research is needed to explore additional variables that can improve overall building energy performance. Studies on wall insulation, ventilation strategies, and the integration of renewable energy systems like solar panels or wind turbines can provide new insights into how buildings can achieve greater energy efficiency and sustainability in the future.

7.3 Future Research Directions

This study emphasizes the critical role of passive design strategies in enhancing energy

efficiency in building construction, specifically within the context of residential buildings. Passive design strategies, which include the optimization of natural light, ventilation, and thermal performance, are essential for reducing energy consumption while maintaining occupant comfort. The integration of these strategies not only lowers energy costs but also contributes to a building's environmental sustainability, aligning with broader global goals of energy conservation and greenhouse gas reduction.

Future research should delve deeper into the potential of advanced facade materials and innovative shading strategies, which have shown promise in improving the thermal performance of buildings. These materials, such as dynamic facades, can adjust their properties based on external weather conditions, allowing for more effective heat and light control. Additionally, smart glass technologies, which allow for the regulation of solar heat gain and daylight penetration, could play a transformative role in improving energy performance. These advancements have the potential to create adaptive building envelopes that respond in real-time to external environmental factors, further enhancing energy efficiency.

Moreover, the impact of occupant behavior on energy efficiency cannot be overlooked. Understanding how occupants interact with their building's systems—such as heating, cooling, and lighting—can provide invaluable insights into optimizing building designs for real-world use. Occupant behavior often deviates from theoretical expectations, leading to discrepancies between predicted and actual energy consumption. By studying how users interact with their environments, researchers can develop more accurate and holistic building guidelines that account for these variations and encourage energy-efficient behavior.

By implementing these evidence-based passive design strategies, building professionals and stakeholders can significantly contribute to the creation of sustainable and energy-efficient residential environments. Such environments not only reduce the environmental impact but also enhance occupant comfort and well-being. Therefore, future research in these areas is crucial for improving building performance and achieving long-term sustainability goals.

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APPENDICES

APPENDIX A: QUESTIONNAIRE SAMPLE

Name of the respondent:……..

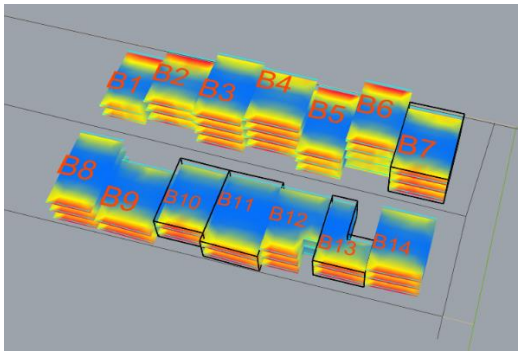
No. and storey of rooms in the house:…….

List of electrical appliances and its usage in the household:

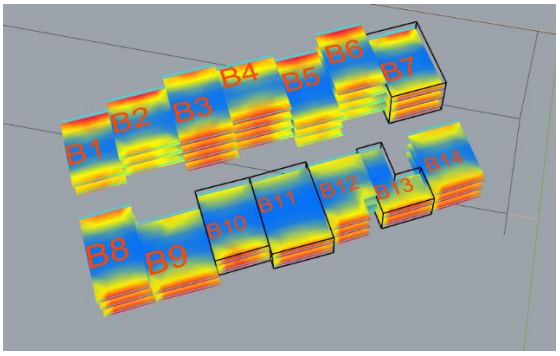
S.N.	Name of Appliance (with Model No.)	Purpose of the appliance	Power rating (in Watts)	Energy star rating (if available)	Daily average usage

Measurement of the house (To be filled by surveyor):

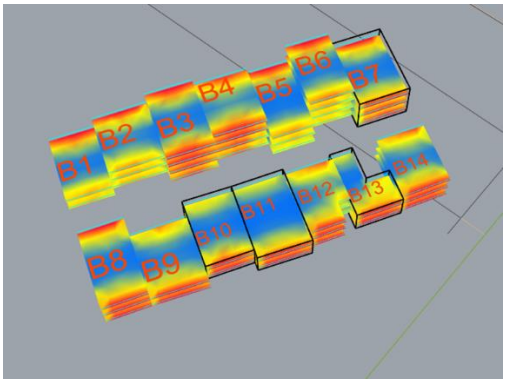
APPENDIX B: CDA OUTPUTS



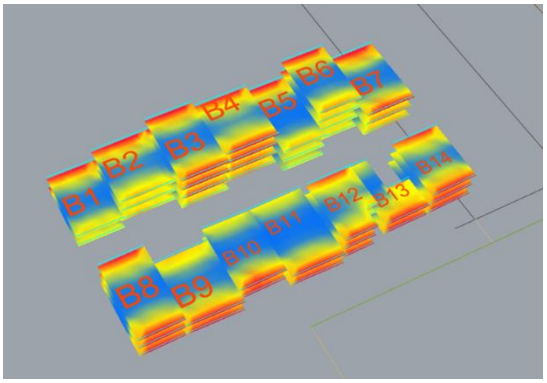
WWR 10% orientation 0°



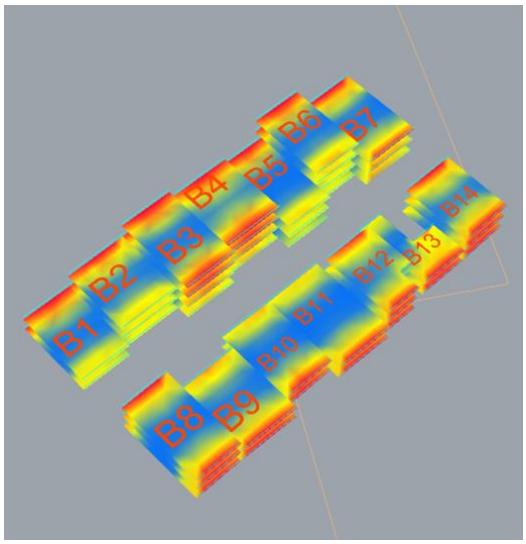
WWR 10% orientation 30°



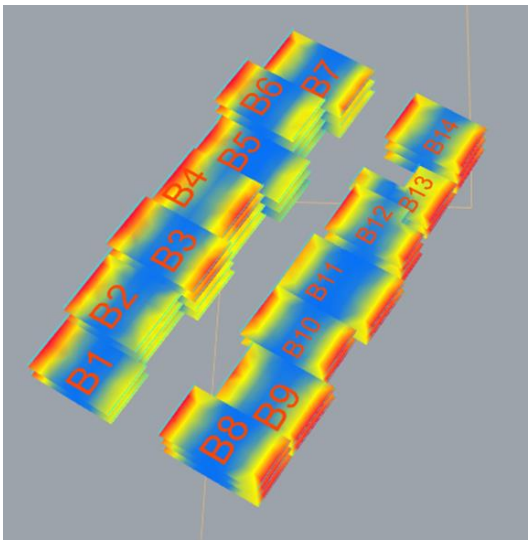
WWR 10% orientation 60°



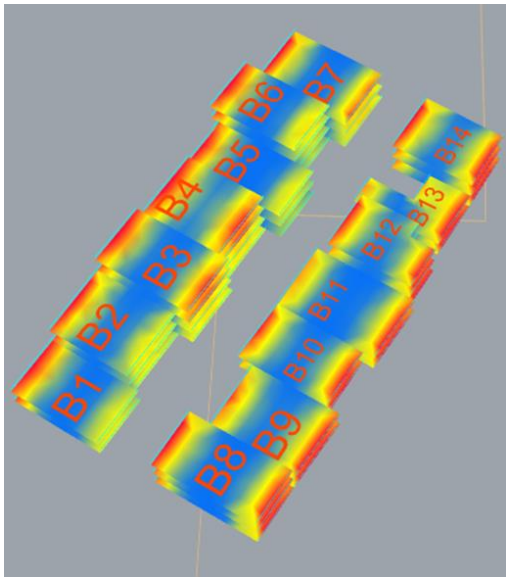
WWR 10% orientation 90°



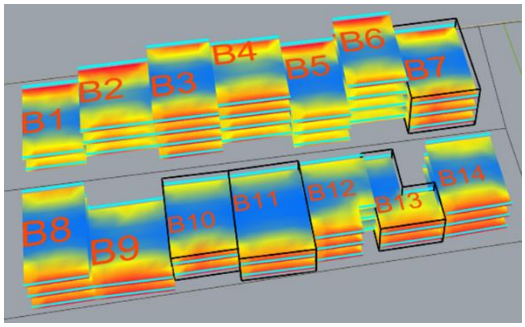
WWR 10% orientation 120°



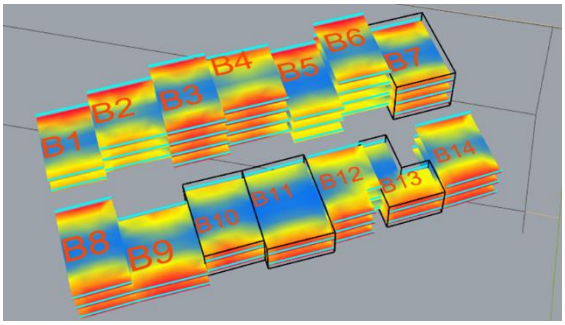
WWR 10% orientation 150°



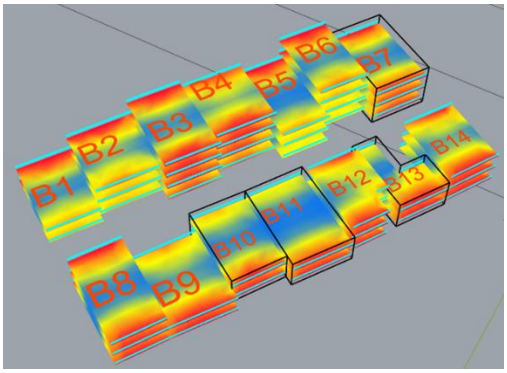
WWR 10% orientation 180°



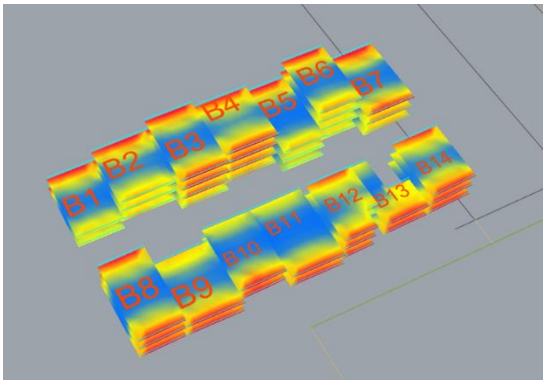
WWR 20% orientation 0°



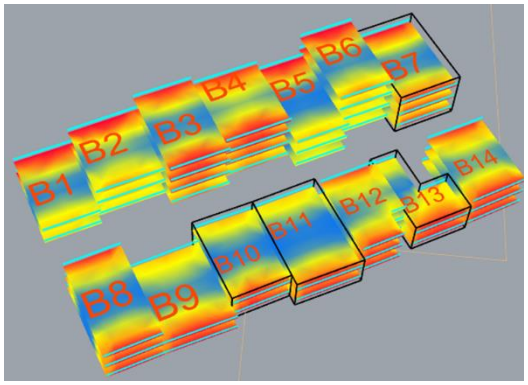
WWR 20% orientation 30°



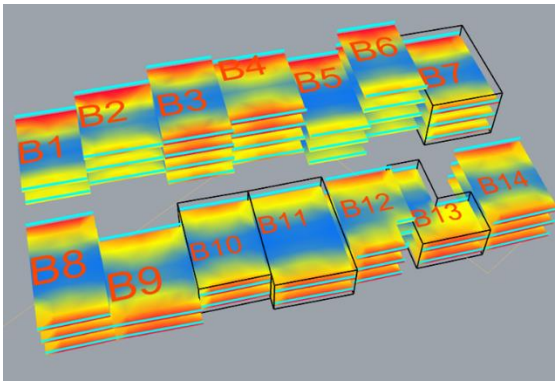
WWR 20% orientation 60°



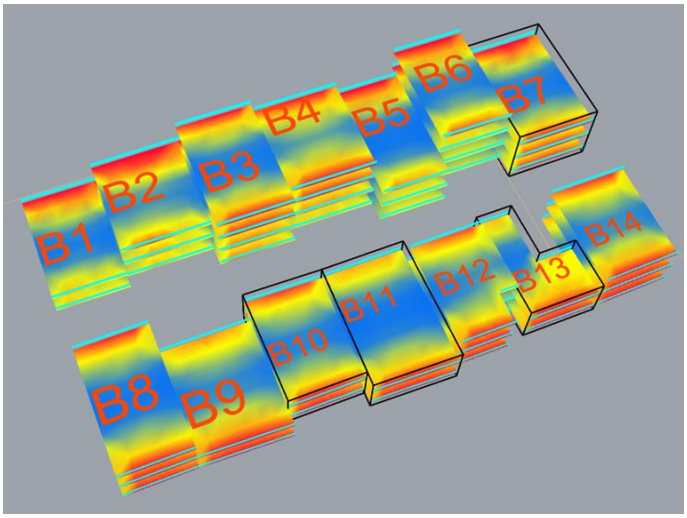
WWR 20% orientation 90°



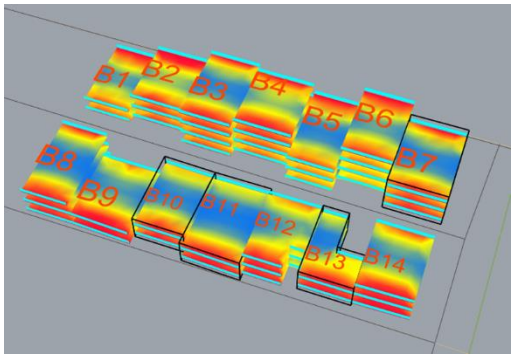
WWR 20% orientation 120°



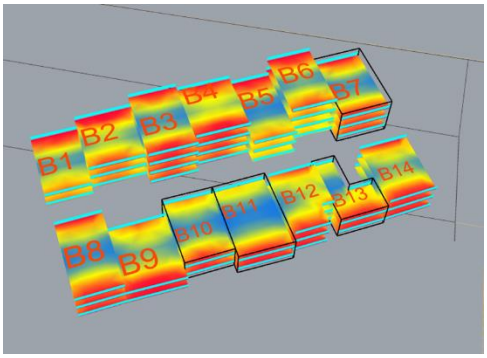
WWR 20% orientation 150°



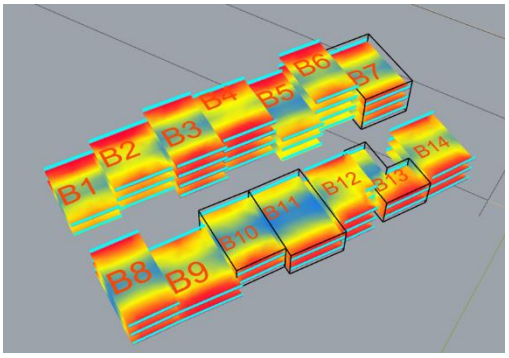
WWR 20% orientation 180°



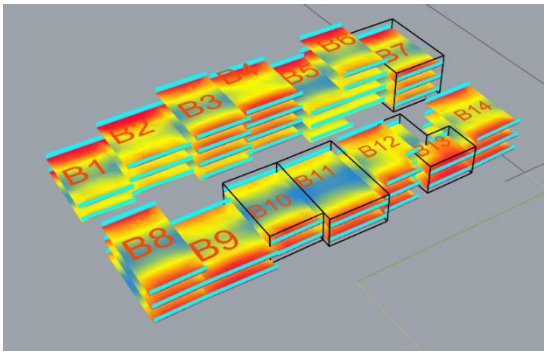
WWR 30% orientation 0°



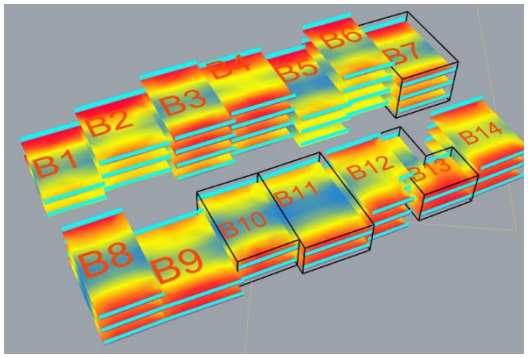
WWR 30% orientation 30°



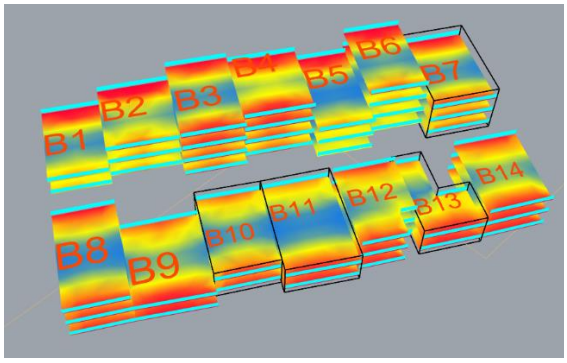
WWR 30% orientation 60°



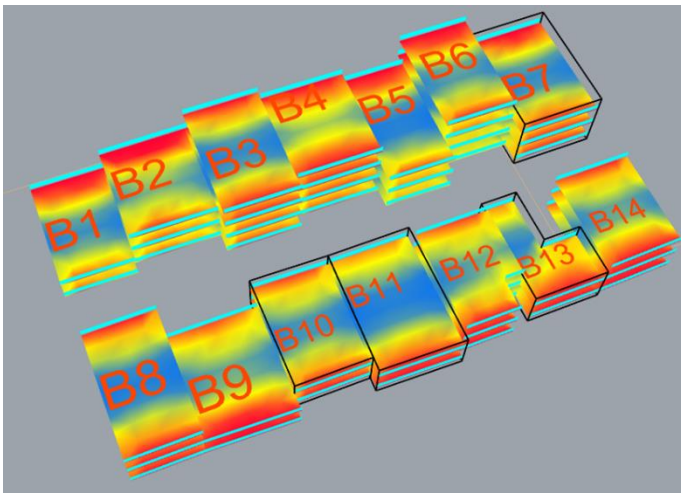
WWR 30% orientation 90°



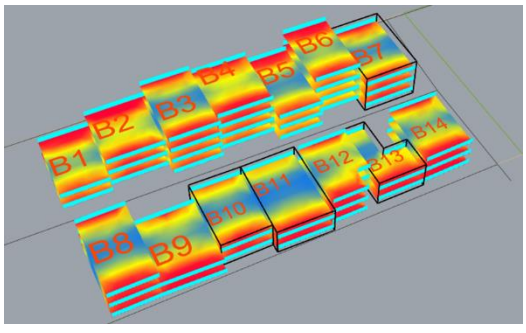
WWR 30% orientation 120°



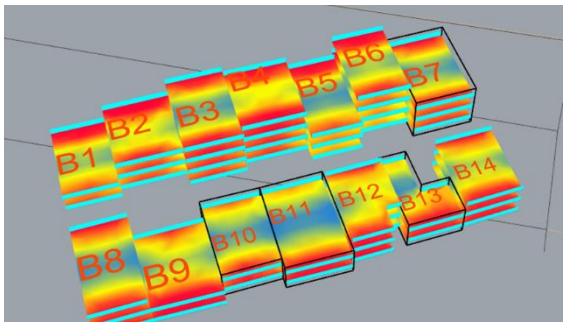
WWR 30% orientation 150°



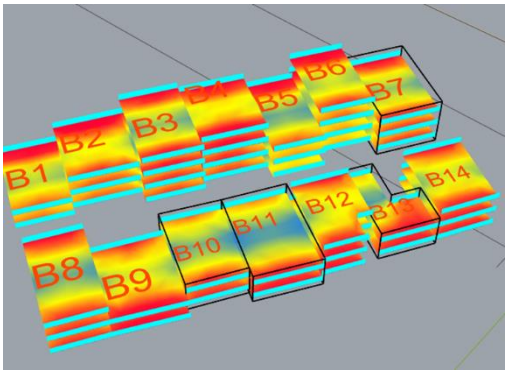
WWR 30% orientation 180°



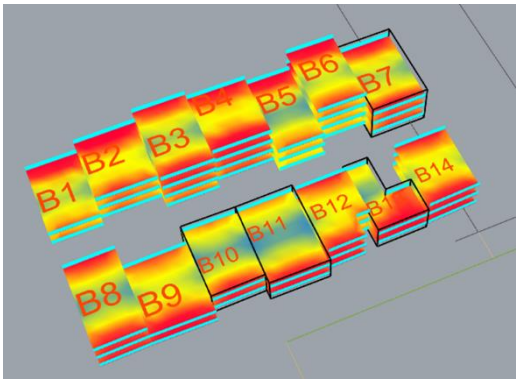
WWR 40% orientation 0°



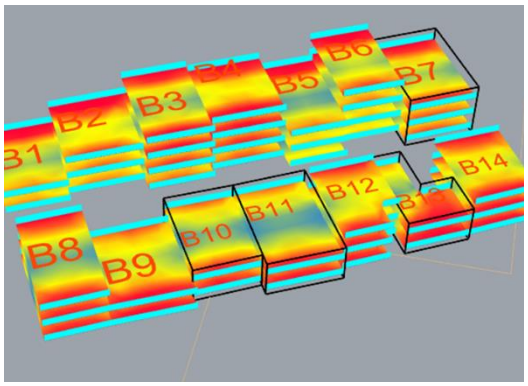
WWR 40% orientation 30°



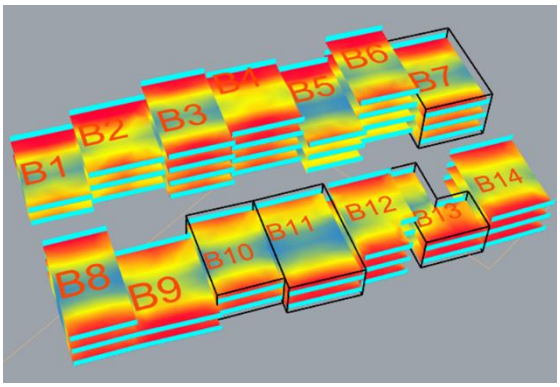
WWR 40% orientation 60°



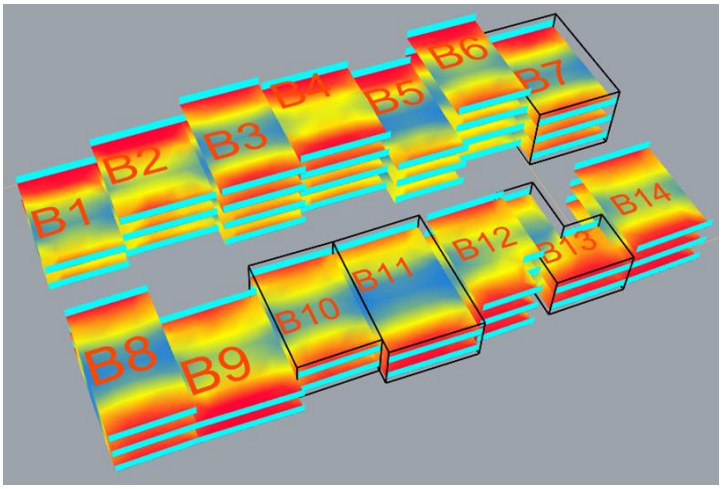
WWR 40% orientation 90°



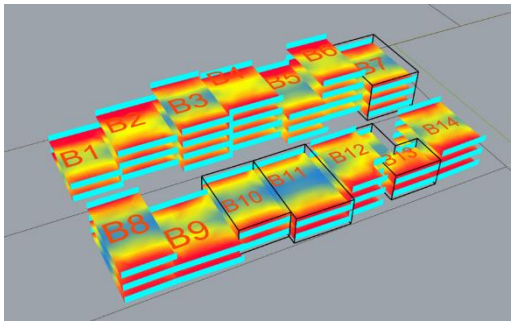
WWR 40% orientation 120°



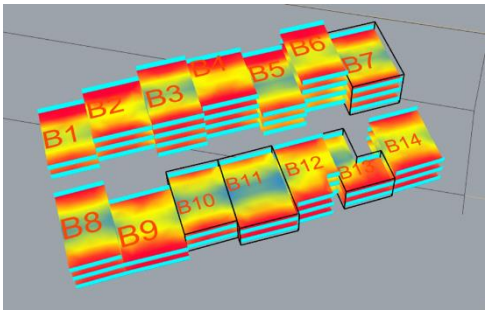
WWR 40% orientation 150°



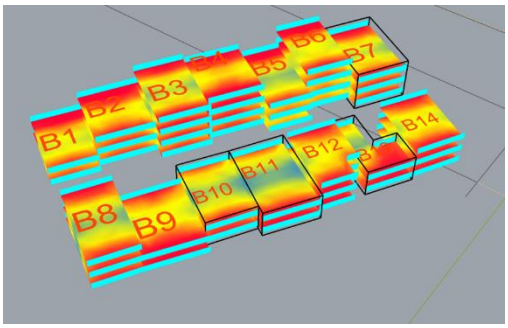
WWR 40% orientation 180°



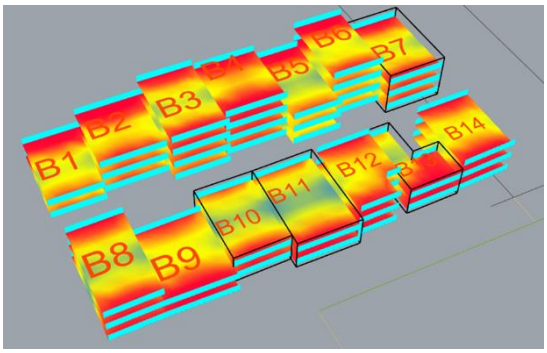
WWR 50% orientation 0°



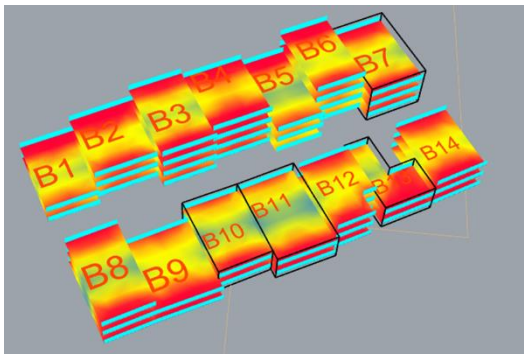
WWR 50% orientation 30°



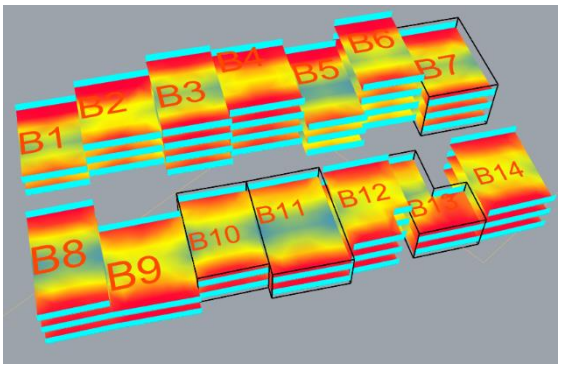
WWR 50% orientation 60°



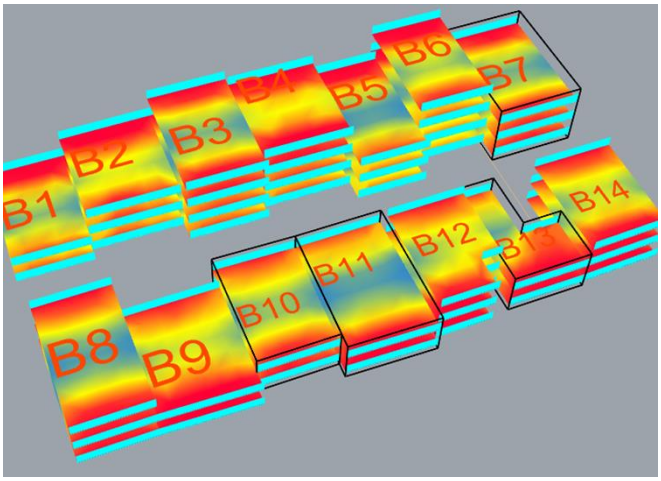
WWR 50% orientation 90°



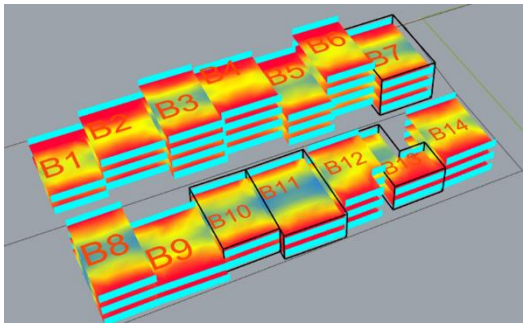
WWR 50% orientation 120°



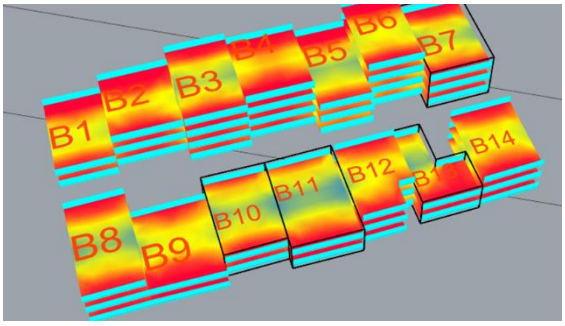
WWR 50% orientation 150°



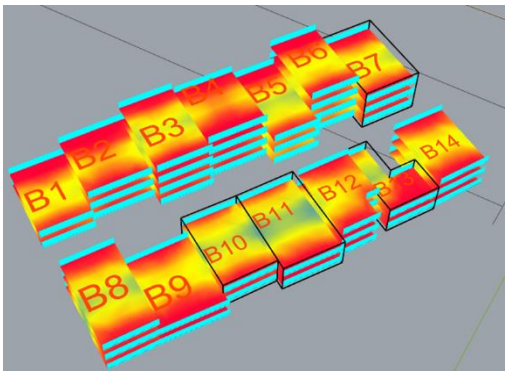
WWR 50% orientation 180°



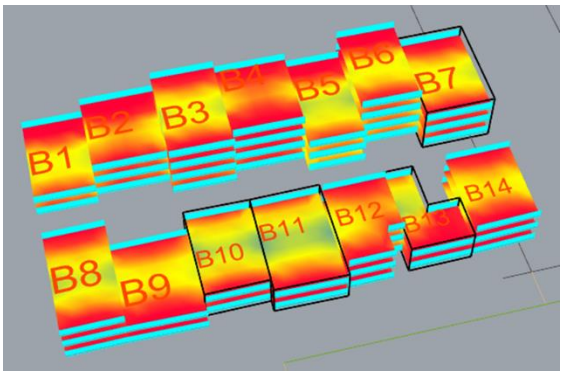
WWR 60% orientation 0°



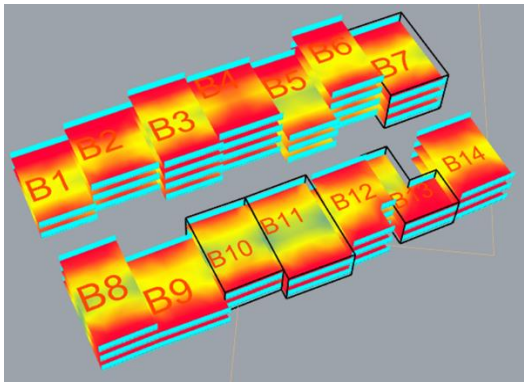
WWR 60% orientation 30°



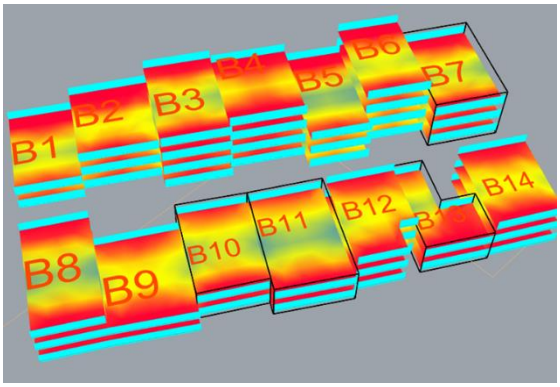
WWR 40% orientation 60°



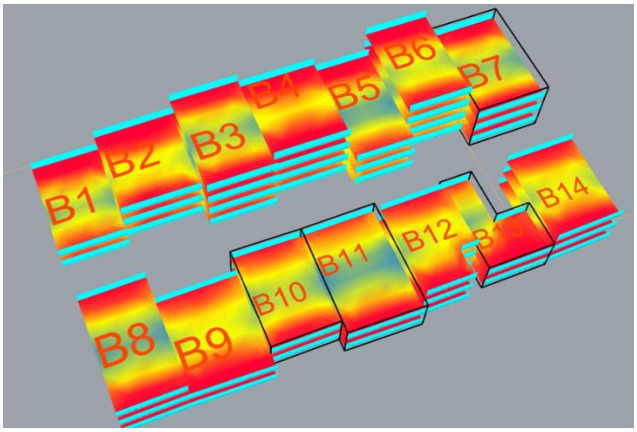
WWR 40% orientation 90°



WWR 40% orientation 120°



WWR 40% orientation 150°



WWR 40% orientation 180°

APPENDIX C: CDA CALCULATIONS

Table (a) CDA values for different orientation with WWR 10%

Building Name	WWR	Orientation						
		O Deg	30 Deg	60 Deg	90 Deg	120 Deg	150 Deg	180 Deg
B1	10	20	22	24	23	23	20	18
B2		24	25	28	28	27	24	21
B3		16	18	21	22	22	19	16
B4		21	24	27	28	28	25	22
B5		17	19	20	20	19	17	15
B6		20	21	23	24	22	20	18
B7		15	18	21	21	21	18	16
B8		14	17	19	20	19	17	15
B9		18	21	23	23	22	21	20
B10		14	15	17	17	17	17	16
B11		14	16	16	17	17	17	15
B12		15	18	21	22	21	20	18
B13		19	20	22	24	24	21	19
B14		17	19	21	23	24	21	19

Table (b) CDA values for different orientation with WWR 20%

Building Name	WWR	Orientation						
		O Deg	30 Deg	60 Deg	90 Deg	120 Deg	150 Deg	180 Deg
B1	20	35	36	38	37	36	34	31
B2		40	41	44	44	42	39	35
B3		28	31	34	35	35	32	29
B4		37	39	42	44	44	41	38
B5		30	31	32	32	31	28	26
B6		34	35	37	38	36	33	30
B7		28	30	34	34	35	32	29
B8		25	28	30	32	32	29	27
B9		30	35	37	37	36	35	34

B10		24	26	28	28	30	30	29
B11		24	26	27	28	29	28	27
B12		26	31	34	36	35	34	31
B13		32	33	36	40	40	37	35
B14		30	33	34	37	39	37	34

Table (c) CDA values for different orientation with WWR 30%

Building Name	**WWR**	**Orientation**						
		O Deg	**30 Deg**	**60 Deg**	**90 Deg**	**120 Deg**	**150 Deg**	**180 Deg**
B1	30	45	46	48	46	46	43	40
B2		52	52	54	54	53	50	46
B3		37	40	43	44	44	42	38
B4		48	50	54	55	55	53	49
B5		38	39	41	40	39	36	35
B6		43	44	47	47	45	42	39
B7		37	40	43	43	44	41	38
B8		33	37	39	41	40	38	36
B9		40	44	47	47	46	45	44
B10		33	34	36	37	38	39	38
B11		31	34	35	36	37	37	36
B12		36	41	44	46	45	44	41
B13		41	43	46	50	50	48	46
B14		40	42	44	47	49	47	44

Table (d) CDA values for different orientation with WWR 40%

Building Name	**WWR**	**Orientation**						
		O Deg	**30 Deg**	**60 Deg**	**90 Deg**	**120 Deg**	**150 Deg**	**180 Deg**
B1	40	52	53	55	53	53	50	48
B2		60	60	62	62	61	58	54
B3		44	47	50	51	52	49	45
B4		56	59	62	63	63	61	58
B5		45	46	47	47	46	43	41
B6		51	51	54	54	53	49	46

B7		44	46	50	51	51	48	45
B8		40	43	46	47	47	45	43
B9		47	52	55	55	53	53	52
B10		40	41	43	43	45	46	45
B11		37	40	41	42	43	43	42
B12		43	49	52	54	53	52	49
B13		49	50	54	57	58	56	54
B14		48	50	52	55	58	55	52

Table (e) CDA values for different orientation with WWR 50%

Building Name	**WWR**	**Orientation**						
		O Deg	**30 Deg**	**60 Deg**	**90 Deg**	**120 Deg**	**150 Deg**	**180 Deg**
B1	50	58	59	61	59	59	56	53
B2		66	66	69	69	68	64	60
B3		50	53	56	57	57	54	50
B4		63	65	68	70	70	67	64
B5		51	51	53	52	51	48	46
B6		57	57	60	60	58	55	52
B7		49	52	56	56	57	54	51
B8		45	48	61	53	53	50	48
B9		53	58	61	61	59	59	58
B10		45	47	49	49	51	52	51
B11		43	45	47	47	49	49	48
B12		49	55	58	60	59	58	55
B13		55	56	59	62	63	61	60
B14		54	56	58	61	64	61	58

Table (f) CDA values for different orientation with WWR 60%

Building Name	**WWR**	**Orientation**						
		O Deg	**30 Deg**	**60 Deg**	**90 Deg**	**120 Deg**	**150 Deg**	**180 Deg**

B1	60	63	64	66	64	64	61	58
B2		71	71	74	74	73	69	66
B3		54	57	61	62	62	59	55
B4		68	70	73	75	75	72	69
B5		55	55	57	56	56	53	51
B6		61	62	64	65	63	59	57
B7		54	57	61	61	62	59	55
B8		49	53	56	57	57	54	52
B9		58	63	66	66	64	64	63
B10		50	52	53	54	56	57	56
B11		47	50	51	52	53	53	52
B12		55	60	64	65	64	63	60
B13		59	61	64	66	67	66	64
B14		59	62	64	66	69	66	63

APPENDIX D: CONFERENCE PAPER

IOE Graduate Conference
[Placeholder for Publication Information]

Temporal Study of Land Use Change in East Kathmandu : A GIS Based Study on Agricultural Land Transformation and Urbanization Trends

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Abstract
Urban expansion and land-use change have become critical challenges in rapidly developing regions. This study examines the spatio-temporal dynamics of land use and land cover (LULC) changes in the eastern part of Kathmandu Valley from 2015 to 2024, with a focus on urbanization trends and their impact on agricultural land. The shift is primarily driven by rapid population growth, economic expansion, and infrastructure development. Our findings reveal a significant increase in built-up areas, accompanied by the loss and fragmentation of agricultural land. This aligns with broader urban sprawl trends observed in other major Nepalese cities, including Kathmandu, Bharatpur, Dhangadhi, and Biratnagar. However, compared to national and global trends, the pattern in eastern Kathmandu exhibits unique characteristics influenced by local planning policies, topographical constraints, and socio-economic factors.
Using high-resolution satellite imagery and GIS-based spatial analysis, we quantify the extent of LULC transformation and explore the relationship between settlement expansion, population growth, and agricultural land conversion. Unlike previous studies that primarily focus on general urbanization trends, our research emphasizes the spatial correlation between demographic shifts and land use changes, filling an essential gap in the literature. The findings underscore the urgent need for sustainable urban planning policies to mitigate uncontrolled urban sprawl and preserve agricultural resources.

Keywords
Temporal ,Land use ,Agricultural, Geo-spatial, Urbanization

1. Introduction

Understanding the dynamics of land use change is of great importance for effective urban planning and sustainable development in rapidly growing urban areas. The research project area, East Kathmandu, has experienced significant changes in land use over the past decade, driven primarily by urbanization and population growth. East Kathmandu, classified for this geospatial study, consists of six municipalities in Kathmandu. Budhanilkantha NP, Gokarneshwor NP, Kaageeshwori Manohara NP, Shankharapur NP, Tarkeshwor NP, Tokha NP. The total area in this region is 232.832 km2 [1]. The population of the project area is 771,908 [2] , and population growth has been 60% over the past decade. Over the past few decades, predominantly agricultural areas have been increasingly directed. This procedure comes primarily from living and commercial development and leads to changes in the local landscape [3].

This study focuses on analyzing the temporal changes in land use, particularly the conversion of agricultural lands, in East Kathmandu from 89.549 km2in 2015 [1] to its new coverage value in 2024. The area's transition from traditional agricultural practices to urban infrastructures reflects broader socio economic shifts and environmental impacts, necessitating a comprehensive spatial analysis.

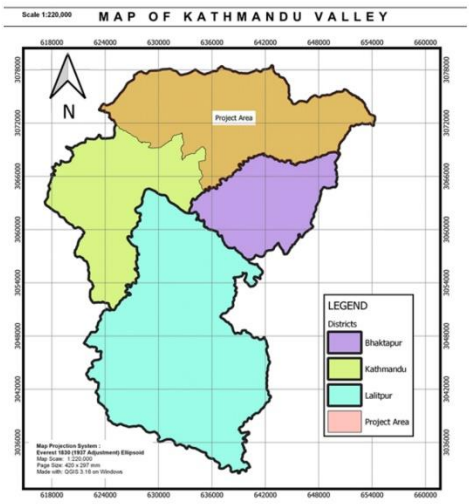

Figure 1: Map of Kathmandu Valley showing Project Area

This study aligns with global, regional, and national research on urbanization and land-use change by examining how rapid population growth and infrastructure expansion drive agricultural land conversion. Globally, urban sprawl has been widely studied in rapidly developing cities, such as in India, China, and Southeast Asia, where farmland loss and environmental degradation are common challenges [4].

Pages: 1 – 7

Similar trends have been observed in Nepal's major urban centers. study highlights a significant annual decline of 2.04% in agricultural land from 1984 to 2000 [5]. A study found that over a period of 20 years (from 1990 to 2010), the Kathmandu district has lost 9.28% of its forests, 9.80% of its agricultural land and 77% of its water bodies [6]. A GIS based study conducted in Pokhara and Bharatpur in 2020 revealed that the built-up area has increased significantly by 300% in Pokhara and by nearly 500% in the Bharatpur during the past 28 years [7].

By employing Geographic Information Systems (GIS) and satellite imagery, this research aims to delineate and quantify these land cover changes, providing valuable insights into the spatial dynamics of urban expansion and its implications for sustainable urban planning. The findings of this study are expected to contribute to the academic understanding of urbanization processes in East Kathmandu and offer practical implications for policymakers and urban planners striving to balance development with environmental conservation and agricultural sustainability. By examining the temporal evolution of land use patterns, this research seeks to inform future strategies for managing urban growth and preserving agricultural heritage in rapidly urbanizing regions.

2. Problem Statement

Rapid urbanization in East Kathmandu, Nepal, has significantly altered land use, particularly through the conversion of agricultural land into residential and commercial areas. This transformation presents major challenges for urban planners and policymakers, affecting the region's socioeconomic structure and ecological sustainability. While many parts of Kathmandu have already undergone extensive urbanization, East Kathmandu still retains a notable portion of agricultural land. However, increasing land plotting and construction activities indicate a rapid transition, making it a critical area for studying ongoing land-use change.

Despite its significance, there remains a gap in understanding the extent, rate, and spatial patterns of agricultural land conversion in East Kathmandu from 2015 to 2024. Previous studies have primarily focused on broader urban trends, often lacking detailed spatial analysis and cadastral data integration. This study addresses these gaps by conducting a comprehensive temporal analysis using Geographic Information Systems (GIS) and high-resolution satellite imagery. The land use and land cover changes have been observed and marked by manual process in the study.

By identifying and quantifying land cover changes, this research aims to elucidate the drivers and consequences of urban expansion on agricultural landscapes. Additionally, it explores the relationship between population growth, settlement expansion, and agricultural land loss, providing critical insights for sustainable urban planning and land management in rapidly developing regions.

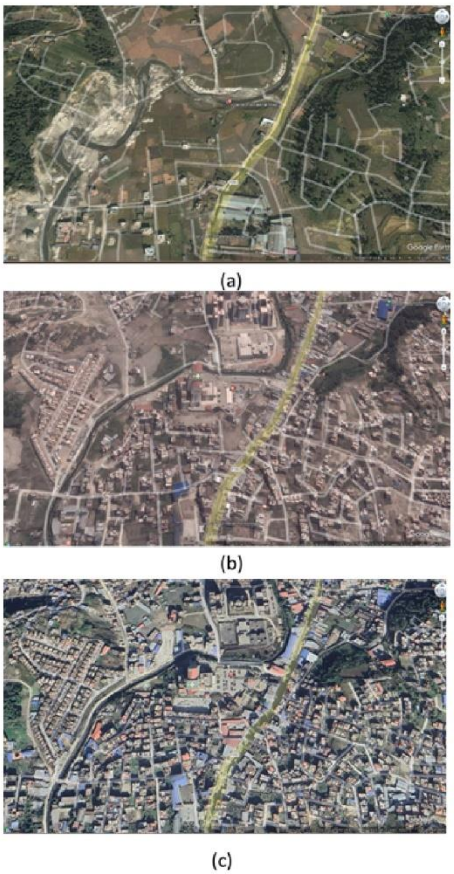

Figure 2: Satellite image of Tokha section of case study area (a) in 2003, (b) in 2015 and (c) in 2024 (Google Earth)

3. Literature Review

Urbanization is a global phenomenon characterized by rapid urban growth and the conversion of rural landscapes to urban areas. Today, more than half of the world's population lives in urban areas, making it an increasingly dense city [8]. The coming decades will bring even deeper changes in the size and spatial distribution of the world population [9]. Driving urban expansion in the Kathmandu Valley context includes physical conditions, accessibility of public services, economic opportunities, land market growth, political situation, planning and guidelines [10]. These factors contribute to the impact of agricultural regions' transformation into residential, commercial and industrial applications, local landscape transformation, and socioeconomic dynamics. In the South Asian context, urbanization trends are particularly pronounced, with cities involved in growth rates. Several

studies around the world demonstrate the effectiveness of GIS in documenting spatial and temporal patterns of land cover changes, allowing researchers to analyze the impact of urbanization on natural environments and agricultural landscapes.In the In context of Nepal , GIS applications were used. [10] used GIS technology to examine the spatial urbanization of Kathmandu Valley. [11] applied GIS to assess the spatial effects of land cover changes on water yield dynamics of water pods in Kathmandu Valley, Nepal. Such studies provide valuable insight into the methods and analytical framework for the temporal analysis of land use changes in East Kathmandu. [12] research emphasising the global outcomes of agricultural conversion, highlighting the loss of productive agricultural regions and the impact on food production systems. Agricultural resources and environmental quality Ensuring growth between the two countries. Research by [13] has resulted in political interventions aimed at promoting compact urban development, reducing spread and maintaining green spaces. These findings are particularly relevant to East Kathmandu, where rapid urbanization requires adaptive politics that reconciliates economic growth, environmental protection and social justice.

4. Objectives

4.1 General Objective:

The general goal of this study is to analyze temporal changes in land use and focus on the transformation of agricultural areas in East Kathmandu from 2015 to 2024 using geographic information systems (GIS) and satellite imagery.

4.1.1 Specific Objective:

The specific objectives of the study are to:
i. To digitalize agricultural land cover in East Kathmandu for the year 2024 using Google satellite imagery.
ii. To quantify and assess the extent of agricultural land conversion.
iii. To study relationship among population, settlement land cover and agricultural land cover changes in the region.

5. Limitations of the Study

The limitations of this study are as follows:

Availability and Quality of Data: The study's accuracy heavily relies on the availability and quality of satellite imagery and GIS data for 2024 and 2015. Variations in data resolution, cloud cover, and data processing techniques could introduce uncertainties in the analysis.

Temporal Resolution: The study covers a specific period (2015 to 2024), which may not capture long term trends or seasonal variations in land use dynamics. Shorter intervals between data points could miss subtle but significant changes.

Classification Accuracy: The accuracy of land cover classification algorithms and methods used in GIS analysis could influence the precision of identifying and mapping agricultural land and urban areas. Errors in classification may affect the reliability of findings.

Scale and Scope: The study focuses primarily on East Kathmandu, which may not fully represent broader regional or national trends in land use change. Extrapolating findings beyond this area should be done carefully.

Data Interpretation and Contextual Understanding: While GIS provides powerful analytical tools, interpreting land use changes also requires contextual understanding of local socio-economic factors, policies, and cultural dynamics, which may not be fully captured during the research process.

6. Research Methodology

6.1 Research Paradigm

Every research is based on a philosophical framework called 'Research Paradigm'. A pattern of beliefs and understandings is offered from which the theories and practices of the research operate. The study will be carried out in mixed method case study research and belongs to pragmatic research paradigm. The pragmatic paradigm implies with mixing of data collection method and data analysis procedures within the research process. In this research, quantitative data on urbanization will be collected from satellite imagery on QGIS, a geographic information system software, while researcher will collect qualitative data in the form of observation of the research area physically as well as on satellite imagery. The methodology begins with the digitalization of satellite imagery to create accurate land cover maps for both 2015 and 2024. These maps serve as the foundation for analyzing changes over time, facilitated by GIS tools that enable spatial overlay, classification, and statistical analysis. The classification process distinguishes between agricultural lands and urbanization trend in Kathmandu East, ensuring a detailed assessment of land use dynamics. The methodology is designed to provide empirical insights into the extent, patterns, and implications of urbanization on agricultural landscapes. Alongside, qualitative observation of the subject will be done to gather information beyond the quantitatively gathered information. Integration of qualitative and quantitative data will lead to a more acceptable conclusion as subjective knowledge alongside objective reality on urbanization will also be considered. The ontological claim of this research is due to increasing migration and certification towards capital city, the population of the valley is increasing while agricultural lands are being encroached to build houses. There are multiple reasons behind encroachment of agricultural land such as increasing attraction towards cities, lesser attraction to agricultural works, political and policy interventions, change in awareness level, etc. The epistemological claim of this research is that relationship between land use patterns of agricultural transformation and urbanization trends will be obtained through quantitative research which can be perceived through temporal analysis of land use pattern and population distribution.

Table 1: Dataset Details

Data Type	Source	Resolution/Scale	Format	Metadata Details
Satellite Imagery	Landsat 7 ETM+ (2000), Landsat 5 TM (2010), Landsat 8 OLI (2020)	30 meters	GeoTIFF	Multispectral images with bands covering visible, near-infrared, and shortwave-infrared wavelengths. Acquired from USGS Earth Explorer.
Topographic Maps	Department of Survey, Government of Nepal	1:25,000 and 1:50,000	Digital	Detailed elevation contours, hydrography, transportation networks, and administrative boundaries.
Land Cover Data	Kathmandu Valley Development Authority (KVDA)	30 meters	Raster	Annual land cover maps of 2015 AD, classified into categories like forest, agriculture, and urban areas.
Ground Truth Data	Field Observation (2024)	-	Observation	Noted the patterns of land cover change in field versus in satellite imagery.
Ancillary Data	Google Earth Pro	Variable	JPEG/KML	High-resolution satellite images and historical imagery for visual interpretation and validation.

6.2 Research Methodology

Digitalization of satellite imagery to create land cover maps for 2015 and 2024 using QGIS software ensures accurate mapping of agricultural, residential, commercial, and other land use categories. Quantification and spatial analysis of land use changes over time, focusing on the conversion of agricultural lands includes calculating changes in land area and identifying trends and patterns. Ground-truthing through physical observation and detailed examination of satellite imagery to complement quantitative findings helps in validating and providing context to the spatial analysis results. GIS-based spatial overlay, hotspot analysis, and statistical methods will identify areas of significant agricultural encroachment and urban expansion, which aids in understanding spatial correlations of urbanization trends and agricultural land transformation.

6.3 Data Sources

6.3.1 Primary Data Sources:

Field Visit and Observation: As the primary data collection techniques, field visit and thorough observation of the research area has been employed. The qualitative as well as quantitative data collected during the field visit and observation has been considered during data analysis phase to lead to a valid conclusion.

6.3.2 Secondary Data Sources:

Satellite Imagery: High-resolution satellite images from Google Earth is used to capture land cover information for the year 2024. These images provide the foundation for identifying and mapping changes in agricultural, residential, commercial, and other land use categories. Digitalization of satellite imagery is done to create a new layer of current state of land cover pattern.

KVDA Data: Land cover data of 2015 AD from Kathmandu Valley Development Authority (KVDA) provides baseline information on land use patterns and changes.

Department of Survey (DOS): Topographic maps and land survey data are utilized as a source and tools to analyze and validate the research objective and results.

Census Reports: Population data from the Central Bureau of Statistics (CBS) are integrated to analyze the relationship between population growth and land use change.

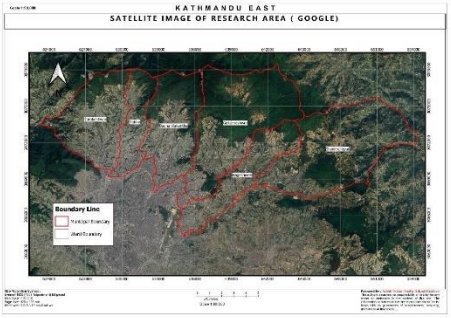

Figure 3: Satellite image with municipal boundary of the research area

7. Spatial Analysis and Discussion

The spatial analysis in this study employs Geographic Information Systems (GIS) to examine the temporal changes in land use across East Kathmandu from 2015 to 2024. Using high-resolution satellite imagery from Google Earth and data from the Kathmandu Valley Development Authority (KVDA), the research focuses on identifying and quantifying shifts in land cover categories, particularly the conversion of agricultural lands to residential, commercial, and other urban uses. The findings reveal significant transformations in East

Kathmandu's landscape over the study period. Agricultural areas have once been steadily decreasing mainly in favour of expanding urban settlements. Quantitative analysis shows a significant increase in residential and commercial areas, particularly along transportation corridors and urban centers. Spatial analysis identifies specific hotspots of land use change, highlighting areas where agricultural encroachment is most pronounced. These hotspots coincide with rapid urban growth and infrastructure development, reflecting patterns of economic expansion and population influx. Moreover, the analysis demonstrates spatial correlations between population growth and the expansion of settlement areas, underscoring the interconnected dynamics of demographic change and land use patterns.

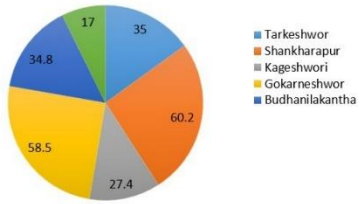

Figure 4: Area of Municipalities in East Kathmandu (in sq.km)

7.1 Land cover distribution

The project area consists of total land of 232 sq.km of land. Largest municipalities in the project area are Shankharapur and Gokarneshwor covering a quarter of total area by each municipality. Smallest municipality in East Kathmandu is Tokha with only 117 sq.km of area.

As per the landcover dataset from KVDA (2015), 39% of the total land in East Kathmandu is categorized as Agricultural land and 22% of the area is covered by residential area, rural settlements and traditional settlements. As of the data collected by research team, it is found out that the settlement area now covers 36% of the total land mass of East Kathmandu, while agricultural coverage has decreased to 25%. It shows the growth rate of 3.8% per year in settlement sector, while agricultural area decreasing at the rate of 1.7% per year.

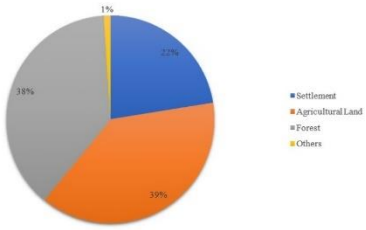

Figure 5: Land cover proportion of East Kathmandu (KVDA, 2015)

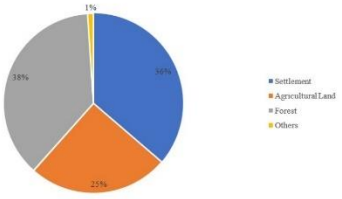

Figure 6: Land cover proportion of East Kathmandu (Research Team, 2024)

Commercial farming has been seen predominant in the region with majority of agricultural land being covered with organized farms, cultivation tunnels and cash crops rather than the traditional and less productive farming. This shows the possibility of future research related to status of commercial farming in the region.

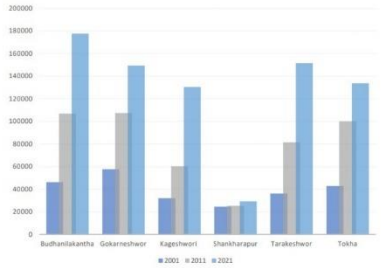

Figure 7: Municipality wise Population of East Kathmandu (CBS, 2021)

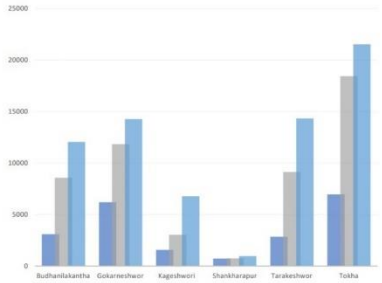

Figure 8: Population density of East Kathmandu (CBS, 2021)

7.2 Population distribution

The population of the project area, East Kathmandu, has been increasing in the last 20 years. In last decade of 2011-2021, population growth rate of the project area is 6% per year [2]. The population density is also observed increasing for the project area. At present population density of Tokha is highest in the region. Meanwhile, population and population density

Item	2015 / 2011	2024 / 2021	% Change (2011/2015 to 2021/2024)
Population (East Kathmandu)	480,000 (2011)	770,000 (2021)	+60.42%
Population Density (per sq. km)	2,069/km²	3,319/km²	+60.42%
Settlement Area (sq. km)	51.04 km² (22%)	83.52 km² (36%)	+63.64%
Agricultural Area (sq. km)	90.48 km² (39%)	58 km² (25%)	35.90%

Table 2: Population and Land Use Changes in East Kathmandu

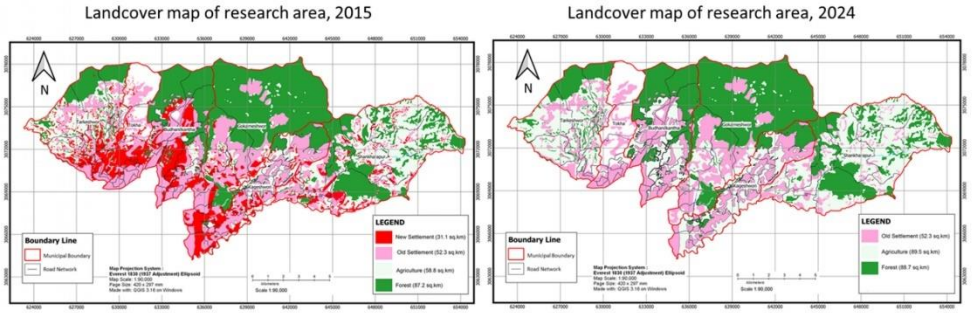

Figure 9: Land use pattern change in study area)

for Shankharapur has shown a silver lining in the cloud with minimal increment in the numbers.

Table 2 shows the percentage changes in population, and land use and land cover in the study period based on the findings of the study and data from CBS. The change in population and settlement area showed a similar trend in the study area.

8. Data Presentation

Different maps have been prepared using QGIS for presenting of the collected data. The maps showing existing landuse and land cover as per KVDA map and the map that has been generated after this study has been presented in FIg 11.

From 2015 to 2024, East Kathmandu has experienced significant changes in its land use and land cover (LULC), driven primarily by rapid urbanization. The population grew by 60.42%, from 480,000 in 2011 to 770,000 in 2021, leading to a sharp increase in population density, which rose from 2,069 people per square kilometer to 3,319 people per square kilometer. This population surge has placed immense pressure on available land, resulting in a substantial increase in settlement areas. The settlement area grew by 63.64%, from 51.04 km² in 2015 to 83.52 km² in 2024, reflecting the expansion of residential, commercial, and industrial zones to accommodate the growing population. Conversely, the area dedicated to agriculture decreased significantly by 35.90%, from 90.48 km² in 2015 to 58 km² in 2024. This reduction in agricultural land is a direct result of urban sprawl, as agricultural areas were converted to built-up spaces to meet the demands of a rising urban population. Overall, the transformation of East Kathmandu over this period highlights the shift from a mixed-use landscape with a strong agricultural base to a densely urbanized area, with far-reaching implications for land use, food production, and the environment.

9. Discussion

The findings of this study highlight the rapid transformation of East Kathmandu's landscape due to urban expansion. The observed shift in land use from agricultural to residential and commercial areas underscores the ongoing urbanization pressures driven by population growth and economic development. The decline in agricultural land from 39% in 2015 to 25% in 2024, coupled with the increase in settlement coverage from 22% to 36%, indicates a significant and consistent trend of land conversion. These trends are similar to the recent study conducted in Nepal [5, 7]. A study conducted in Kathmadu revealed 83% in built- up areas between 2013 and 2016 [14]. This data is more than our study as our study area is less urbanized area as compared to overall Kathmandu. This transformation, occurring at an annual growth rate of 3.8% for settlement areas and an annual decrease of 1.7% in agricultural land, raises concerns regarding food security, ecological balance, and sustainable urban development. More than ten SDGs are linked with land issues, and are not achievable if land issues are not addressed [15]. The findings of the research recommends for a planned procedure for land use trends in this growing urban sprawl.

10. Conclusion

The study of land use changes in East Kathmandu from 2015 to 2024 underscores the profound impact of urbanization on agricultural lands. The findings reveal a substantial reduction

in agricultural areas, particularly in the core regions near Kathmandu city center, where rapid conversion to residential and commercial use has occurred. This trend is largely driven by significant population growth and the subsequent demand for housing and infrastructure.

In contrast, areas on the outskirts, such as Shankharapur and Western Tarkeshwor, have experienced less impact from urbanization. These regions still retain a considerable portion of their agricultural land, indicating a spatial disparity in the effects of urban expansion across East Kathmandu. The use of Geographic Information Systems (GIS) and satellite imagery has been instrumental in analyzing and quantifying these land use changes. These tools have provided valuable empirical data, offering insights into the patterns and extent of agricultural land transformation. Such data are crucial for policymakers and urban planners in understanding the dynamics of land use and making informed decisions.

This study highlights an urgent need for balanced urban planning that prioritizes the preservation of agricultural land while accommodating urban growth. Sustainable development strategies must be implemented to manage the expansion effectively and ensure environmental sustainability. This includes integrating green spaces, promoting vertical growth, and establishing strict land-use regulations to protect remaining agricultural areas.

In conclusion, while urbanization is inevitable and often beneficial for economic development, it is imperative to adopt a holistic approach to urban planning in East Kathmandu. By doing so, it is possible to achieve a sustainable balance between development and the conservation of vital agricultural resources, ensuring long-term resilience and quality of life for the region's inhabitants.

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The authors particular gratitude to the Department of Architecture and Urban Planning at Pulchowk Campus, IOE, TU. Their provision of essential resources, facilities, and a supportive academic setting was invaluable to the research process. The department's ongoing encouragement played a crucial role in bringing this project to fruition.

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Finally, the authors wish to express their deep appreciation for the camaraderie and collaborative spirit of their classmates and colleagues. Their support and encouragement fostered a positive and productive research environment.

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APPENDIX E: CONFERENCE CERTIFICATE AND LETTER OF APPROVAL

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in recognition of an invaluable contribution as

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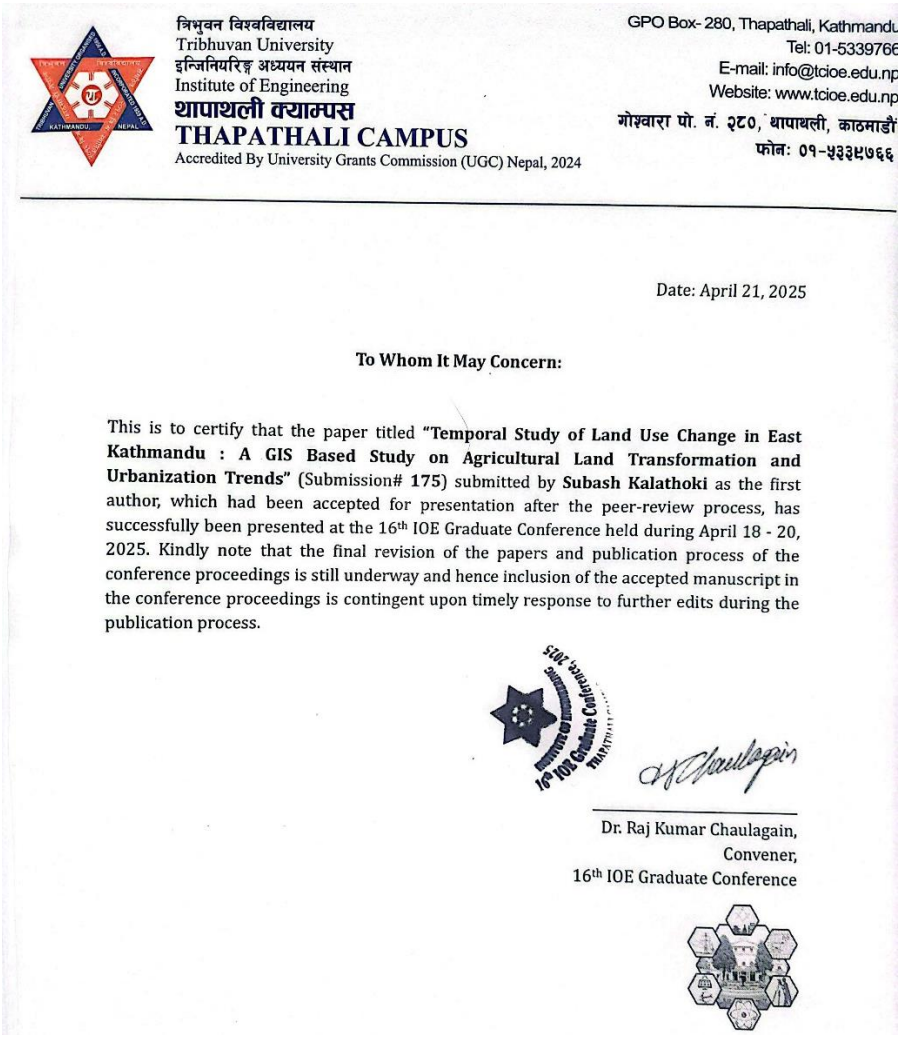

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To Whom It May Concern:

This is to certify that the paper titled **"Temporal Study of Land Use Change in East Kathmandu : A GIS Based Study on Agricultural Land Transformation and Urbanization Trends"** (Submission# **175**) submitted by **Subash Kalathoki** as the first author, which had been accepted for presentation after the peer-review process, has successfully been presented at the 16th IOE Graduate Conference held during April 18 - 20, 2025. Kindly note that the final revision of the papers and publication process of the conference proceedings is still underway and hence inclusion of the accepted manuscript in the conference proceedings is contingent upon timely response to further edits during the publication process.

Dr. Raj Kumar Chaulagain,
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APPENDIX F: PLAGIARISM TEST REPORT

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