ISSN 1728-7715 (print)
ISSN 2519-5050 (online)

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING

VOLUME THIRTY FIVE
2025 (Second Issue)

ISSN 1728-7715 (print)
ISSN 2519-5050 (online)

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING

VOLUME THIRTY FIVE
2025 (Second Issue)

Department of Architecture & Planning,
NED University of Engineering & Technology, City Campus
Maulana Din Muhammad Wafai Road, Karachi.

ISSN: 1728-7715 (Print)
ISSN: 2519-5050 (Online)
Journal DOI: https://doi.org/ 10.53700/jrap_neduet

Online publication available at:
www.jrap.neduet.edu.pk

JRAP Follows the best practice guidelines
of Committee of Publication Ethics (COPE)

Publication Designed at Department of Architecture and Planning
NED University of Engineering & Technology, Karachi

Published by NED University Press

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING

Panel of Referees

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING

Panel of Referees

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING

Published by	NED University Press, Department of Architecture and Planning, NED University of Engineering and Technology, Karachi, Pakistan. Email: ned_universitypress@neduet.edu.pk URL: neduet.edu.pk/ned-university-press
Journal Management Support Team	Farida Ghaffar (Assistant Professor, Department of Architecture and Planning, NED University of Engineering and Technology, Karachi) Sarah Sarmad (Lecturer, Department of Architecture and Planning, NED University of Engineering and Technology, Karachi) Fariha Tahseen (Lecturer, Department of Architecture and Planning, NED University of Engineering and Technology, Karachi)
Layout and Composition	Azeem Ahmed Khan
Printed by	Khwaja Printers, Karachi

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING

Introduction

Focusing on research works relevant to the fields of architecture and planning, the Journal of Research in Architecture and Planning (JRAP) explores issues of relevance to both scholars and practitioners in the field of architecture, urban design, urban planning, built form heritage and conservation. JRAP was initiated in 2000 as a peer reviewed journal, initially published annually, however, since 2011 its frequency has increased to biannual. In addition to the papers received through our regular submission process, the two volumes also include papers selected from those presented at the annual Conference of Urban and Regional Planning, hosted by the Department of Architecture and Planning at NEDUET. Contributions to the journal on general topics are accepted any time of the year, and incorporated in upcoming issues after going through a peer review process. A post conference review is also undertaken for the selection of conference papers, before their publication. JRAP holds the privilege of being the first peer reviewed journal in the discipline of architecture and planning, published from Pakistan. Contributions are received from across the globe and on average half the papers included in JRAP are from international scholars.

As of 2018, the category entitled ‘Young Scholar’s Contribution’ has been included in the Journal. In this category, papers from young faculty and early career scholars are accepted and editorial assistance and peer review feedback is provided to improve the research papers. One such paper is published under the head ‘Young Scholar’s Contribution’ within each issue of JRAP.

Aims and Scope

The primary objective of JRAP is to provide an international forum for the dissemination of research knowledge, new developments and critique in architecture, urban design, urban planning and related disciplines for the enrichment and growth of the profession within the context. The journal focuses on papers with a broad range of topics within the related discipline, as well as other overlapping disciplines. JRAP publishes a wide range of research papers which deal with indepth theoretical reviews, design, research and development studies; investigations of experimental and theoretical nature. Articles are contributed by faculty members, research scholars, professionals and other experts. The Editors welcome papers from interested academics and practicing architects. Papers published so far have been on topics as varied as Housing, Urban Design, Urban Planning, Built Environment, Educational Buildings, Domestic Architecture, Conservation and Preservation of Built Form. All back issues are openly accessible and available online on the Journal’s official webpage: http://jrap.neduet.edu.pk/online_journal.html.

CONTENTS

EDITORS' NOTE

It is a pleasure to present Volume 35, Issue 02 of the Journal of Architecture and Planning, which brings together five diverse and timely contributions addressing critical themes in contemporary urbanism, technology integration, sustainability, and socio-spatial well-being. Collectively, these papers underscore the evolving responsibilities of architects, planners, and allied professionals as they navigate complex environmental, technological, and social challenges across South Asia and beyond.

The issue opens with a paper which advances the conversation on urban mobility by introducing an agent-based modelling framework capable of simulating dynamic interactions between vehicles, pedestrians, and signal systems. The study highlights the delicate trade-offs between efficiency and walkability, demonstrating the potential of calibrated digital twins to support evidence-based decision-making in traffic policy and urban design.

In the second paper of the issue the authors explore how BIM, as an integrative digital environment, can enhance sustainable design outcomes. The paper illustrates how early-stage performance analysis and cross-disciplinary collaboration can reshape conventional design processes, shortening project timelines while promoting environmentally responsive architectural solutions.

The third article addresses the emerging need for clean mobility infrastructure. Employing AHP-based weighting and GIS-driven suitability mapping, the study identifies optimal locations for solar-powered EV charging stations and proposes a complementary mobile application to mitigate range anxiety—an important contribution for the transition toward greener transportation systems.

Urban form and spatial character take center stage in the fourth paper. Through extensive surveys and documentation, the researchers reveal the scale and prevalence of urban voids—spaces often perceived as lifeless or neglected. By reframing these voids as "spaces of potentiality," the study opens new avenues for their ecological, cultural, and social reintegration, offering insights for more vibrant and inclusive urban futures.

The issue concludes with the paper on abandoned railway landscapes in Sri Lanka. Grounded in theories of urban decay and social capital, this mixed-methods investigation examines how deteriorated railway landscapes affect community well-being. The findings point to significant dissatisfaction and weakened social cohesion, but also propose adaptive reuse and participatory urban strategies to transform these neglected corridors into community-centered assets. Together, these contributions enrich ongoing discourse on sustainable design, digital innovation, mobility systems, and human-centered urban transformation.

The volume also contains a book review of 'Understanding Karachi's Architecture: A Documentation of Public Buildings', written by Dr. Suneela Ahmed and Madiha Salam. This important contribution sheds light on Karachi's architectural evolution through the careful documentation of its public buildings, offering insights into the city's sociocultural layers, design influences, and shifting urban identity.

Editorial Board

JRAP
JOURNAL OF RESEARCH IN ARCHITECTURE & PLANNING

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING
Volume 35 Issue 2
ISSN (P) 1728-7715 - ISSN (E) 2519-5050
Journal DOI: www.doi.org/10.53700/jrap_neduet
Issue DOI: www.doi.org/10.53700/jrap3522025

BALANCING PEDESTRIAN AND VEHICULAR NEEDS IN URBAN ENVIRONMENTS: AN AGENT BASED SIGNAL TIMING STUDY

Nida Batool Sheikh*, Muhammad Mashhood Arif**, Ahmad Adeel***

Article DOI:
www.doi.org/10.53700/jrap3522025_1

Article Citation:
Sheikh N. B. et. al., 2025, Balancing Pedestrian and Vehicular Needs in Urban Environments: An Agent Based Signal Timing Study, *Journal of Research in Architecture and Planning,* 35(2). 1-17.

* Doctoral Candidate, Department of Architecture and Urban Planning, Faculty of Engineering and Architecture, Ghent University, Belgium.
nidabatool.sheikh@ugent.be
ORCID: 0009-0002-1434-0666
** Ph D., Department of Planning, Geograpy and Environmental Studies, University of the Fraser Valley, Canada.
mashhood.arif@ufv.ca
ORCID: 0000-0002-7881-3402
*** Ph D., Assistant Professor, Urban Planning and Architectural Design Department, German University of Technology in Oman, Muscat, Oman.
ahmad.adeel@gutech.edu.com
ORCID: 0009-0002-4147-1509

ABSTRACT

Urban environments are increasingly challenged by the need to accommodate rising travel demand while preserving walkability, safety, and public-realm quality. Aggregate signal-timing methods often miss how micro-scale behavior or geometry changes shape delay and movement. The study develops an agent-based model of a mixed-use downtown grid in which vehicles, pedestrians, and signal controllers act as autonomous agents. The framework enables planners to test signal retiming, driver-courtesy campaigns, and adaptive control before deployment. The study aims to assess how modest design and behavioural interventions influence performance across different travel modes and planning priorities. Results show a clear pedestrian–vehicle trade-off and an interior signal-cycle length that minimizes total system delay. Increasing driver courtesy yields large reductions in pedestrian delay with limited impacts on vehicles. The study concludes that agent-based modeling can align operational performance with urban-planning objectives and recommend embedding calibrated digital twins into planning workflows for evidence-based evaluation of zoning decisions, traffic policy, and street design. Finally, because the model is intentionally stylised, its outputs are best interpreted as context-dependent heuristics rather than site-specific prescriptions. For operational use, the framework can be lightly calibrated with GIS-derived network geometry and local volumes and then applied to compare scenarios, rather than to forecast absolute delay levels.

Keywords: Agent-based modelling, signal timing, pedestrian delay, urban planning, traffic safety.

INTRODUCTION

Modern cities face a paradox: they must move people and goods quickly while also meeting broader urban-planning goals such as liveability, equity, and decarbonisation. Traditional four-step and static-equilibrium models aggregate behaviour and therefore struggle to reproduce the non-linear congestion, route-choice feedbacks, and land-use interactions that dominate metropolitan travel patterns (Bastarianto et al., 2023).

Agent-Based Modelling (ABM) addresses this shortcoming by representing each traveller, vehicle, or land parcel as an autonomous agent that perceives, decides, and learns in a shared environment. A recent systematic review of 213 peer-reviewed studies shows an eight-fold growth in transport-oriented ABM publications since 2015 and identifies “integration with urban-form decision making” as a top research frontier (Divasson-Jaureguibarria and Macarulla, 2025). This momentum reflects ABM’s ability to capture micro-level heterogeneity (e.g., demographic attributes, risk attitudes) and reveal macro-level patterns, traffic waves, mode shifts, spatial clustering, that emerge from countless local interactions.

The urban-planning community is simultaneously deploying ABM to test how zoning codes, developer incentives, and demographic shifts reshape long-term travel demand. A three-dimensional agent model of Toronto, for instance, demonstrates how household, developer, and municipal-policy agents co-produce densification corridors that later influence rapid-transit ridership (Ullrich et al., 2024). Earlier integrated frameworks have already linked land-use choice, activity-travel microsimulation, and dynamic traffic assignment in a single ABM pipeline (Pendyala et al., 2012), laying the groundwork for today's multi-scale hybrids.

Policy-facing studies are now fusing these strands. A multi-agent analysis of low-carbon incentives in Fuzhou showed that licence-plate restrictions combined with carbon-trading credits could shift 18 % of daily car trips to public transport or walking within five years—an effect that conventional nested-logit forecasts underestimated by nearly half (Zhang et al., 2024). Such evidence underscores ABM's value as a unifying platform where transport operations, land-use evolution, and behavioural policy levers can be explored concurrently.

Yet two gaps persist. First, many transport ABMs validate against traffic counts or travel-time datasets but rarely cross-check against land-use or pedestrian-flow observations, limiting their credibility for integrated planning. Second, few studies quantify the joint optimisation space where signal-timing decisions interact with pedestrian priorities and built-form constraints—a synergy central to emissions, accessibility, and public-realm quality. To address these gaps, this study develops a behaviourally rich ABM that co-simulates pedestrians and vehicles in a compact urban grid to identify the fixed-time signal cycle length that minimises total system waiting time, asking in particular: which signal interval yields the lowest combined pedestrian and vehicular delay when individual interactions are modelled at the agent level?

LITERATURE REVIEW

Agent-based modelling (ABM) is increasingly recognised as one of the most promising approaches for capturing the behavioural complexity that links transport operations with urban-form evolution. Meta-analyses of ABM research highlight an eight-fold growth in transport-related publications from 2015 to 2022, reflecting a shift away from aggregate four-step models that obscure heterogeneity and toward frameworks that explicitly simulate travellers, vehicles, and land parcels as autonomous agents (Bastarianto et al., 2023; Divasson-Jaureguibarria and Macarulla, 2025).

Agent-based modelling carries distinct advantages by assuming that agents dynamically interact with their environment. These interactions lead to behavioural variation, allowing for flexible experimentation, policy testing, and system-wide analysis (Macal and North 2010). Abbas, Shaheen, and Amin (2015) offer a foundational overview of agent structure, environmental context, and system-level emergence—concepts illustrated in (Figure 1).

Modern pipelines such as UrbanSim–MATSim, SILO–MATSim and ActivitySim–MATSim connect land-use change, activity schedules and traffic flow, enabling planners to simulate zoning schemes or pricing tools with immediate feedback on accessibility, equity, or emissions (Nicolai & Nagel, 2015). Interactive visualisation interfaces overlaying these models have allowed urban designers to iteratively test street

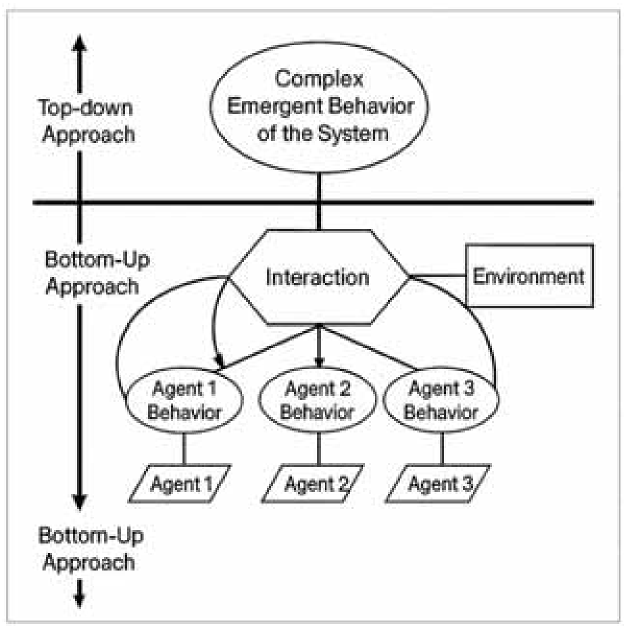


Figure-1: Conceptual structure of a bottom-up agent-based system, illustrating individual agent behaviours and interactions with the environment.

hierarchies and building footprints, strengthening design–transport integration (Maheshwari et al., 2024). Across these studies a compact set of micro-scale indicators repeatedly surfaces as critical for reproducing emergent network phenomena.

The literature emphasises population and fleet size, which establish demand thresholds above which congestion waves become self-sustaining (Manley et al., 2014), and signal timing, the classic lever in both fixed-time optimisation and multi-agent reinforcement-learning controllers that can reduce corridor delay by more than twenty per cent (Kwesiga, Guin, and Hunter, 2025). Vehicle dynamics are captured through acceleration, deceleration and speed-limit, parameters rooted in kinematic and psychophysical car-following rules that recreate stop-and-go oscillations (Newell, 2002; Kesting and Treiber, 2008). Intersection geometry feeds into probability of turning, where small shifts in turning likelihood alter effective capacity by double-digit percentages (Habtemichael and Picado-Santos, 2013). Pedestrian pre-crossing behaviour is distilled to time to crossing, while driver courtesy, represented by Basic-politeness, governs voluntary yielding—both vital for modelling shared spaces and unsignalized crossings (Zhuang and Wu 2014; Li et al. 2023).

Microsimulation of pedestrians reinforces the transport–urban-planning nexus. Social-force, cellular-automata and rule-based models such as "Intend-Wait-Cross" employ parameters analogous to time to crossing and basic politeness to capture heterogeneous gap acceptance and compliance at crossings, enabling planners to test curb extensions, refuge islands and signal phases in silico (Rasouli and Kotseruba, 2022; Kaziyeva et al., 2023). Dynamic 3-D visualisation layers allow architects and stakeholders to experience simulated crowd flows alongside static design renderings, further dissolving the divide between traffic engineering and urban design (Brändle et al., 2009).

On the operations side, ABM-driven reinforcement-learning systems treat each signal head as an intelligent agent, continuously adjusting lights interval in response to evolving queues and pedestrian arrivals. Field-calibrated studies demonstrate that such decentralised controllers outperform actuated or coordinated fixed-time plans while still respecting pedestrian priority windows (Wang et al. 2021). The same architecture can embed reward terms for bus priority or emissions, allowing policy-makers to quantify trade-offs before hardware deployment.

Sustainability, health and equity concerns deepen the relevance of ABM for urban planning. Open-source platforms now merge land-use change, traffic emissions and population exposure modules, producing block-level health-impact maps for proposed zoning or pricing scenarios (Staves et al. 2023). Case studies from Fuzhou and Mexico City show that combinations of licence plate restrictions, carbon trading, and fuel taxe, modelled through agents endowed with income, preferences, and elasticity attributes, can shift up to one fifth of car trips toward public or active modes, with distributional effects that vary sharply by income and neighbourhood (Guerra et al., 2018).

Despite rapid progress, calibration protocols seldom reconcile traffic counts with land-use or pedestrian-flow observations, computational limits constrain city-wide pedestrian ABMs, and integrated optimisation of signal timing, pedestrian priority and built-form geometry remains rare (Bastarianto et al., 2023; Kaziyeva et al., 2023; Divasson-Jaureguibarria and Macarulla, 2025). Addressing these challenges requires lightweight yet behaviourally rich models that trace how carefully chosen micro-scale indicators propagate upward to shape street-level experience and urban performance.

METHODS AND MATERIALS

Choice of NetLogo as the Modelling Platform

NetLogo is a research-grade ABM environment whose core abstractions—turtles (mobile agents), patches (grid cells), links, and an observer—support fine-grained spatial interaction with minimal overhead (Tisue & Wilensky, 2004; Wilensky & Rand, 2015; Parker et al., 2003). Agents move on a patch lattice that functions as a discretised streetscape, allowing vehicles and pedestrians to sense local conditions and react at per-tick (≈1 s) resolution (Kumar & Mitra, 2006).

Three factors drove the choice. (1) The native grid eliminates custom spatial data structures, so interaction rules are expressed in a few lines (Railsback et al., 2017). (2) The model library includes traffic/pedestrian exemplars that accelerate prototyping—important under internship timelines (Tisue & Wilensky, 2004). (3) The language's compact syntax and thorough documentation allow non-programmers to understand, modify, and validate behavioural rules without sacrificing rigour (Sklar, 2007).
The interface is deliberately transparent: two

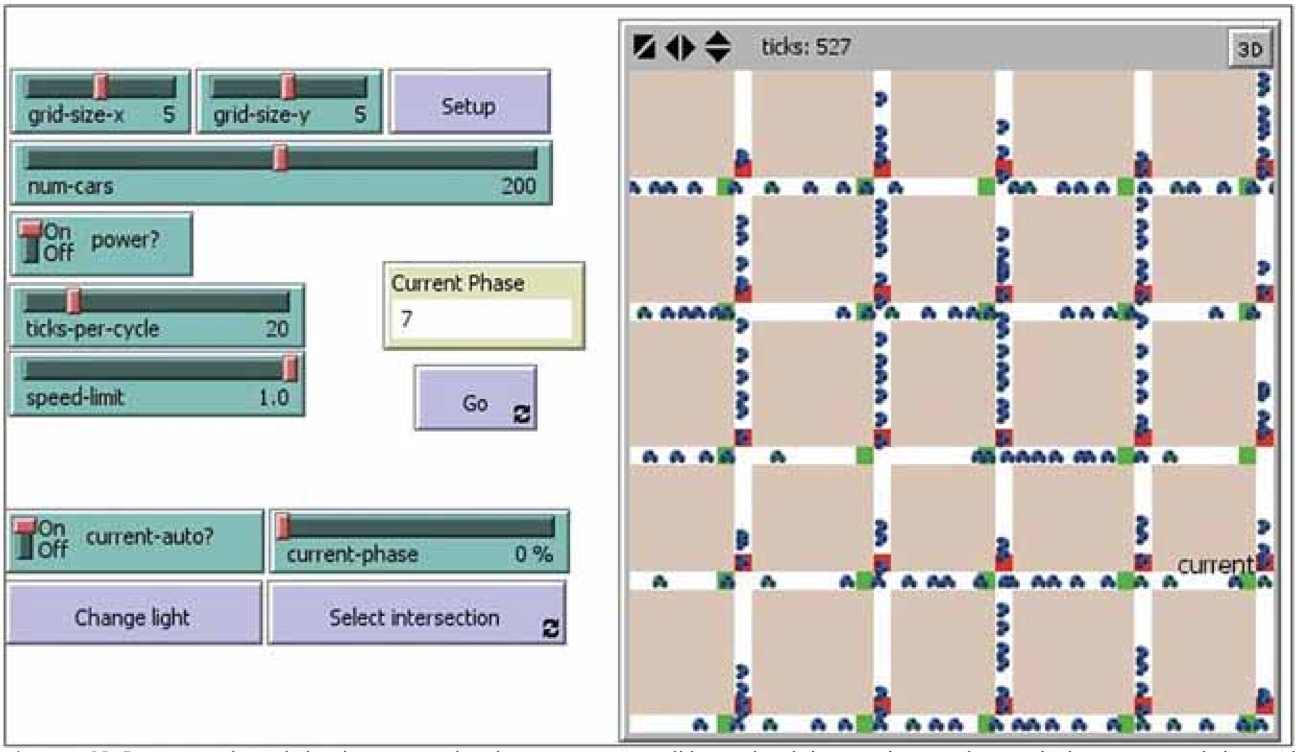


Figure-2: NetLogo control panel showing setup and go buttons, parameter sliders and real-time monitors used to manipulate agent populations and behavioural rules during runtime.

buttons—setup (initialise) and go (advance time)—plus a small set of sliders (e.g., num-cars) enable rapid sensitivity probing. More elaborate runs add plots, choosers, and monitors, but the workflow remains initialise → run → observe → adjust (Tisue & Wilensky, 2004). Figure 2 shows this layout, with the graphics window animating agent movements and control widgets exposing key parameters.

Study Area and Network Representation

The NetLogo world is a 51 × 51 patch lattice with 20 m × 20 m patches, yielding a ~1.02 km × 1.02 km footprint. The network is an orthogonal "Manhattan" grid: two-lane, bidirectional arterials run N–S and E–W at 200 m spacing and form four identical signalised junctions at the cardinal points. Every approach has 8 m zebra crossings so pedestrians can clear in a single green without refuges.

Roadway patches (dark grey) are grouped into centre and curb lanes; although each lane is one patch wide, internal bookkeeping assigns vehicles to lanes and maintains per-lane queues. Sidewalks (light grey) flank both sides of every road. Kerb patches sit between roadway and sidewalk as buffer/waiting areas where pedestrians queue before crossing.

Static land-use patches (e.g., residential SW, offices NE, pocket parks/streetscape elements) provide visual context for face validity and debugging only; they do not interact with agents. The world is non-wrapping: perimeter patches act as walls. Vehicles spawn at four entry nodes on the north and west edges and exit via symmetric sinks to the south and east, mimicking inbound commuter flows. Pedestrians spawn uniformly on sidewalks within the commercial core to reflect frontage footfall.

The orthogonal grid, uniform agent traits (single courtesy distribution; constant walking speed), and two-mode scope (private cars, pedestrians) are deliberate simplifications to surface core dynamics. Patch (20 m) and tick (~1 s) scales provide face validity rather than kinematic fidelity; weather, enforcement, land-use feedbacks, transit/cyclists/-freight, and fine-grained signal coordination are outside the present model.

Our NetLogo implementation draws conceptual inspiration from the Town – Traffic & Crowd simulation User

Table 1: Baseline parameters for the mixed pedestrian-vehicle agent-based simulation.

Indicator	Value / Range	Description
Num-of-people	250	Population count, matching median pedestrian - vehicle ratios in EU core cities
Num-of-cars	150	Fleet size representing typical urban traffic proportions
Lights-interval	5 - 50 ticks (5 - 50s)	Traffic signal cycle length (green - amber - red sequence)
Acceleration	0.182 patch s^{-2} (3.64 m s^{-2})	Vehicle acceleration rate (IDM-calibrated)
Deceleration	0.057 patch s^{-2} (1.14 m s^{-2})	Comfortable braking rate for vehicles
Speed-limit	0.9 patch s^{-1} (18 m s^{-1} ≈ 65 km h^{-1})	Maximum vehicle speed
Prob-of-turning	0.40	Probability of a vehicle turning at intersections
Time-to -crossing	Mean = 1000 ticks (≈ 17 min)	Timer triggering pedestrian movement to crossings
Basic-politeness	μ = 50 (scale 0 - 100)	Driver courtesy level in yielding to pedestrians

Community Model and generalises it into a research-grade framework by re-engineering the spatial discretisation (20-m patch lattice with per-lane queues and stop-line reservations), formalising courtesy and gap-acceptance parameters for crossing interactions, and adding tick-level logging with fixed-time and PID-overlay experiments for Δ-effect analysis (Lukas, 2014).

Indicator Selection and Parameterisation

A synthesis of empirical research identifies eight micro-scale variables that influence emergent traffic behaviour in urban agent-based simulations (Table 1). The number of pedestrians is often grounded in observational studies of pedestrian flow dynamics in urban centres (Helbing et al., 2005), while the number of vehicles is based on modal split and saturation levels found in mid-sized European cities (Kitamura et al., 2000). The lights-interval, referring to traffic signal timing, is widely recognized as a critical control parameter affecting both vehicular delay and pedestrian crossing opportunity (Stevanovic et al., 2009).

Acceleration and deceleration behaviours are typically drawn from validated car-following models, where calibrated parameters reflect comfortable and responsive driving patterns (Hoogendoorn, van Arerm and Hoogendoorn, 2014). The speed limit variable accounts for regulatory and geometric constraints in urban traffic environments and is a key determinant in travel-time modeling (Sun and Kim, 2021). At intersections, turning probability significantly shapes vehicle trajectories and intersection throughout, often estimated from empirical turn movement data (Sato and Akamatsu, 2008). The time-to-crossing for pedestrians is driven by perceptual and response-time studies of street-crossing behaviour (Kalatian, 2021), while driver politeness, a behavioural trait affecting voluntary yielding, is informed by socio-psychological models of driver decision-making under uncertainty (Schroeder and Rouphail, 2011).

Terminology and Measurement Definitions

For clarity, we define how time, space, behaviour, and performance are represented. These are explanation about important terminologies that are being used in the model:

Tick (simulation step): One update of the global clock that advances all agents and signals in lock-step; here ≈ 1 s unless otherwise noted. "Tick-level logs" means recording each metric once per tick.

Patch / patch size: A fixed grid cell in NetLogo; we map 1 patch = 20 m × 20 m to relate simulated distances to physical units (metres, km). Patches tile the 1 km^2 study grid and serve as the basis for lane length and capacity.

Agents: Mobile turtles (vehicles, pedestrians) and signal objects governed by rules for perception, decision, and action; an observer actor performs logging/aggregation.

Lights-interval (cycle length): The full signal cycle (green + amber + red) expressed in ticks. Related terms: green split (share of green within the cycle), amber and all-red clearances (safety buffers), and offsets (phase alignment across junctions).

Approach / queue length: An approach is one inbound arm of a junction. Maximum queue length is the largest number of queued vehicles observed on that approach during a run; used with delay to diagnose stability.

Pedestrian delay: time waiting on the kerb before stepping into a legal crossing window.

Vehicle delay: time spent stopped or creeping in a signal queue relative to free flow at the stop line. Per-tick logs yield mean delay by mode.

Level of Service (LOS): Standard A–F grading of operational quality from the Highway Capacity tradition: A/B = low delay; C = moderate/stable delay; D = high delay approaching instability; E = very high; F = breakdown. We report LOS to contextualise the interior optimum (~15 s cycle).

Basic-politeness (courtesy): 0–100 scale governing driver yielding probability at crossings.

Time-to-crossing: internal pedestrian timer that triggers movement toward crossings.

Gap acceptance: implicit threshold (function of courtesy and local speeds) for a safe cross.

PID controller (adaptive overlay): A proportional–integral–derivative feedback rule that nudges Lights-interval a few ticks up/down based on recent imbalance between pedestrian and vehicle delay; used for simple adaptive control in Scenario C.

Replication / seed and windows: Each scenario is repeated under unique random seeds; a warm-up (5 000 ticks) clears transients, followed by a steady-state window (45 000 ticks) for analysis.

Δ (delta) effects: We emphasise comparative changes (scenario vs baseline) rather than absolute forecasts, consistent with a stylised laboratory model.

In this study, patches depict road lanes, sidewalks and contextual land-use blocks, while turtles represent traffic lights, vehicles and pedestrians, each governed by dedicated procedures. This arrangement supports rapid experiments on signal timing, demand levels and driver-pedestrian behaviour, yet keeps the link between on-screen dynamics and underlying code explicit, an invaluable feature when results must be communicated to planners who may not read source code.

Traffic Model Construction and Simulation

Agent Architecture: Vehicles, Pedestrians and Signals

All dynamic entities are encapsulated in three turtle types—vehicles, pedestrians and traffic lights—which share a common six-module architecture comprising (i) intrinsic traits, (ii) mechanics, (iii) perception/decision logic, (iv) action execution, (v) communication and (vi) a local knowledge base.

Vehicles inherit mechanical limits of 0.182 patch/s^2 acceleration, 0.057 patch/s^2 deceleration and a 90 patch/s speed ceiling. A 1.2 s reaction time and a normally distributed *Basic-politeness* score (μ = 50, σ = 15) govern yielding when pedestrians enter a zebra crossing. At each tick, the driver module applies a simplified Newell car-following rule—accelerate, cruise, brake or stop—and a 0.40 turning-probability test at junctions (Newell, 2002).

Pedestrians spawn on sidewalks, strolling at 1.4 m/s^1 until an internal Time-to-crossing timer (≈ 1 000 ticks) expires. They then move to the nearest wait-point, accept the first 3-s gap or yielded vehicle, and traverse at constant speed while a social-force repulsion prevents pedestrian–pedestrian overlap (Helbing et al., 2005).

Traffic lights are finite-state turtles cycling through green, amber (3 ticks) and red, with a 1-tick all-red for clearance. The complete cycle equals the scenario's Lights-interval. Signals broadcast their state so that approaching vehicles and waiting pedestrians can react synchronously.

Spatial Environment and Interaction Rules

In terms of spatial environment, road links have two lanes per direction, each lane mapped to a row of patches. Nodes encode intersections, driveways, or bus-stop bays, while interior blocks host static land-use patches (residential, office, trees) used only for face validity. Sidewalk strips flank every carriageway, and a kerb patch separates footpath and traffic lanes, providing a buffer where pedestrians wait and evaluate gaps. Links are non-wrapping: vehicles enter at four inflow gates on the north and west edges and exit via sinks to the south and east, yielding net circulation without artificial inflow inflation.

For interaction rules., vehicles maintain speed unless a slower leader, a red signal, or a crossing pedestrian appears within 10 patches; if braking cannot restore safe headway, they stop. Pedestrians toggle between waiting and crossing states, updating gap acceptance every 0.3 s (sub-tick timer). Traffic lights decrement an internal timer and broadcast state changes; downstream agents parse these in the same tick. Because all agents share a global clock, signal changes, driver reactions, and pedestrian steps occur in a consistent order, avoiding race conditions.

Scenario Design, Runtime, and Metrics

For design & runtime, we test ten fixed-time scenarios by varying Lights-interval from 5 to 50 ticks in 5-tick steps. Each scenario is replicated 10 times under unique random seeds to characterise stochastic variance. Runs comprise a 5,000-tick warm-up followed by a 45,000-tick sampling window (≈ 12.5 h). A baseline with Lights-interval = 25 ticks anchors all comparisons (Δ effects for delay, queues, and throughput).

During the sampling window the observer records, every tick, (i) mean pedestrian waiting time at the kerb, (ii) mean vehicle waiting time at the stop line (relative to notional free-flow), (iii) maximum queue length per approach, and (iv) throughput (vehicles cleared per approach and total). Tick-level logs stream to CSV and are tagged with scenario ID, replication ID, and seed, enabling reproducible post-processing in R. For reporting and figures, tick logs are aggregated to 1-min and 5-min bins to smooth short-term noise; we present means with 90th-percentile (p90) tails to capture long waits that shape perceived service. Across replications, we summarise mean ± SD and plot 95% CIs from bootstrapped samples. Quality checks include a stationarity screen (rolling mean/variance in the sampling window) and a duplicate-seed guard.

Verification, Validation and Sensitivity

To perform code verification, tick-level unit tests assert legal phase progression (with amber/all-red), mutual exclusion on reserved patches (stop lines/crosswalks), FIFO queues with safe headways, vehicle conservation, lawful pedestrian entry, and yielding consistent with the courtesy parameter.

Similarly for external validation, baseline approach delays and pedestrian crossing times—scaled at 20 m patches and ≈1 s ticks—were compared with weekday observations from a similarly sized Belgian town; means and p90 tails were within ±12%, and scenario ordering (shorter cycles favour pedestrians; longer cycles favour vehicles) aligned with field intuition.

To check sensitivity/robustness, one-at-a-time ±20% perturbations (volumes, walking speed, courtesy, clearances), ten independent replications per scenario, and a small Latin-hypercube probe (±10% joint variation) all preserved the monotonic pattern: pedestrian delay ↓ and vehicle delay ↑ with longer cycles, with an interior minimum in total delay. These checks provide face validity for the stylised grid; corridor use still requires calibration to local counts, crossing times, and queue distributions.

RESULTS

This section translates the modelling framework described earlier into observable system behaviour. We begin with an appraisal of interface design and functional capabilities, then move to quantitative analyses of delay, congestion, signal-timing sensitivity, and scenario tests.

Design and Function

The simulation interface was conceived as a self-contained laboratory in which users can initialise scenarios, manipulate parameters on the fly, and watch system-level consequences unfold in real time. Pressing Setup flushes every data buffer, returns the sliders to their defaults, and repopulates the network with a fresh cohort of agents; a single click on Go then advances the global clock in one-second

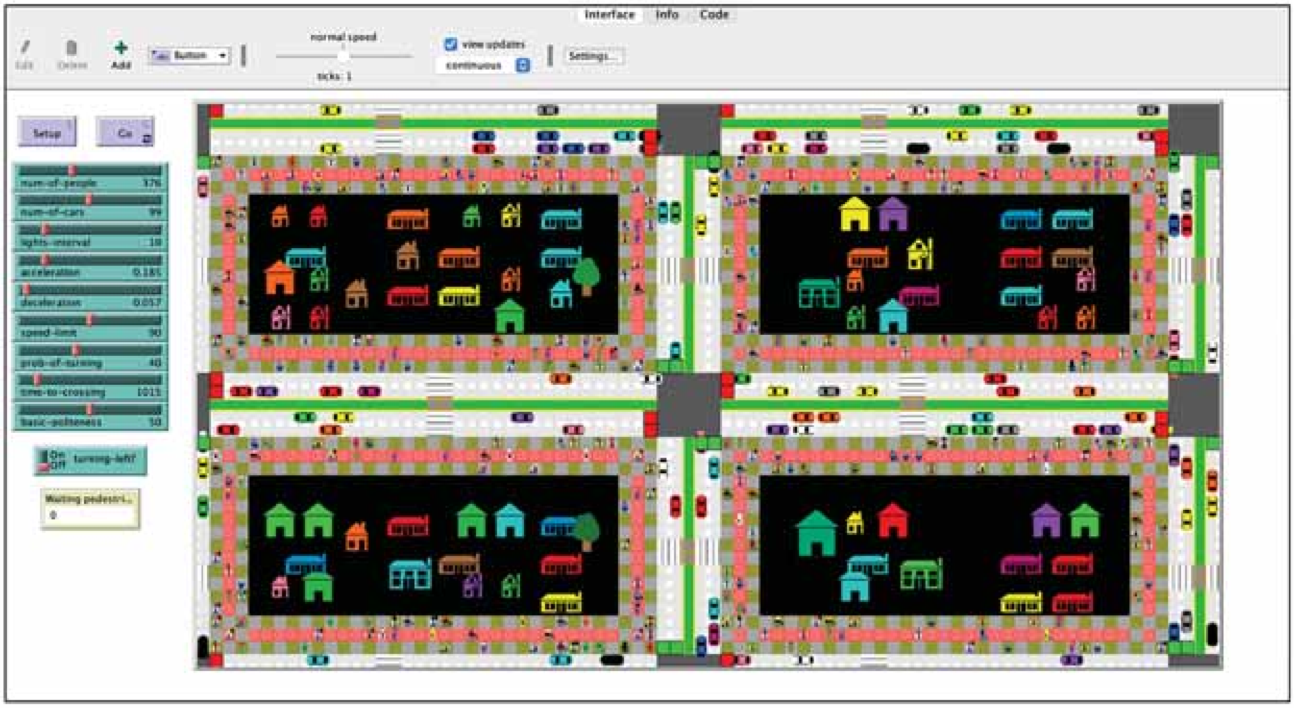


Figure-3: NetLogo control panel and graphics window showing parameter sliders on the left and the simulated 2-D traffic scene on the right.

ticks, ensuring that vehicle kinematics, pedestrian decisions, and signal phases remain synchronised by a common scheduler. Because NetLogo treats time as a discrete counter, all state changes are perfectly reproducible under identical random seeds, an essential property when delay curves are later aggregated across replications. Two demand sliders—num-cars and num-people—can be moved during a run, instantly injecting or removing agents so that analysts can test how the network absorbs sudden peaks or lulls. The graphics window offers a conventional plan view that colour-codes free-flowing vehicles, queued vehicles, pedestrians, and signal states; a toggle button opens an optional 3-D perspective (via the Perspective extension) that projects agents into depth, a useful aid when demonstrating the model to architects or planners who need to visualise sight lines and level changes. Traffic-signal objects are equally malleable: the user can add or delete individual heads mid-simulation, and the Lights-interval slider retimes every cycle without forcing a restart. Amber and all-red clearances are exposed as separate numeric inputs, allowing safety margins to be lengthened for school-crossing scenarios or shortened for

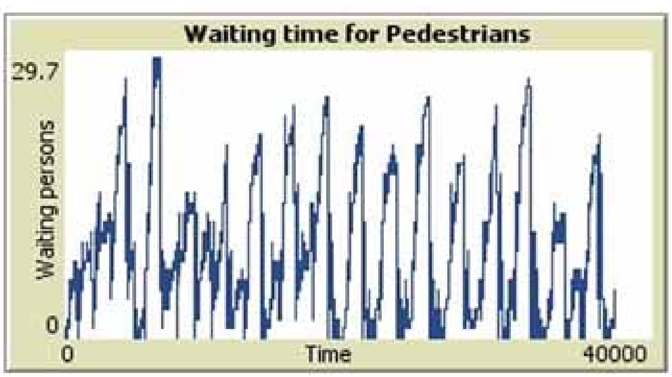


Figure-4a: Pedestrian waiting time vs. pedestrian population (left)
*Figure-4b:*Vehicle waiting time vs. vehicle count; point A marks the lowest congestion (right).

throughput studies (Figure 3).

Behind the scenes, every vehicle records its entry tick, exit tick, and cumulative delay in a private list; the observer agent harvests these data once per second, calculates mean delay for each mode, the longest queue on every approach, and total throughput, and streams the results to CSV while simultaneously updating rolling plots on the interface.

Because the GUI gives immediate visual confirmation—queue bars lengthen, delay charts spike or flatten—users develop an intuitive grasp of cause and effect. A particularly instructive slider is Basic-politeness. Raising the mean courtesy value causes drivers to yield more readily at crossings, and the pedestrian-delay plot plunges within a few ticks, making an otherwise abstract behavioural variable tangible.

The vehicle agents themselves inherit a full kinematic signature, speed, acceleration, deceleration, turning probability, and a personal time-to-crossing counter, so even when static at a red light they occupy exactly one patch, preserving lane capacity as a simple ratio of lane length to patch size. Because patch length, tick duration, and vehicle speed are all known, simulated velocity translates directly into physical units (metres per second), enabling credible comparisons with field data.

The influence of these interface elements is apparent in the delay traces. In the results (Figure 4a), the waiting-time profile for pedestrians oscillates as courteous drivers yield in clusters: higher politeness values flatten the peaks because pedestrians are released sooner, whereas lower values generate pronounced spikes. The plots vehicle delay against active vehicles (Figure 4b) count and illustrates how unsynchronised red phases distribute queues across the grid; the dip marked corresponds to a moment when an upstream signal turns green just as a downstream platoon clears, briefly emptying the link. Together, these diagnostics confirm that the GUI not only satisfies functional requirements but also supports an exploratory workflow in which users can pose a question, adjust a slider, and observe a quantitatively traceable answer within seconds.

Evaluation Results

Experimental set-up

For the baseline experiment the model instantiates 250 pedestrian agents and 150 vehicle agents on the 1 km² grid. Free-flow speed is limited to 0.9 patch s^{-1}, which equals 18 m s^{-1} (≈ 65 km h^{-1}) given the 20 m patch length. Acceleration and deceleration bounds are held at 0.182 patch s^{-2} (3.64 m s^{-2} in physical units). Behavioural defaults—40 % turning probability, Time-to-crossing = 1 000 ticks, and Basic-politeness = 50—match empirical observations for medium-density European centres. Each run begins with a 5 000-tick warm-up to dissipate transients, followed by 45 000 ticks (≈ 12.5 h) of steady-state data capture.

Signal-Timing Sweep

To isolate the impact of fixed-time control, the Lights-interval parameter is stepped from 5 to 50 ticks in 5-tick increments. Ten replications at unique random seeds are executed for each setting, yielding 100 runs. Tick-level delay logs are consolidated in R; scenario means and 95 % confidence intervals populate (Table 2).

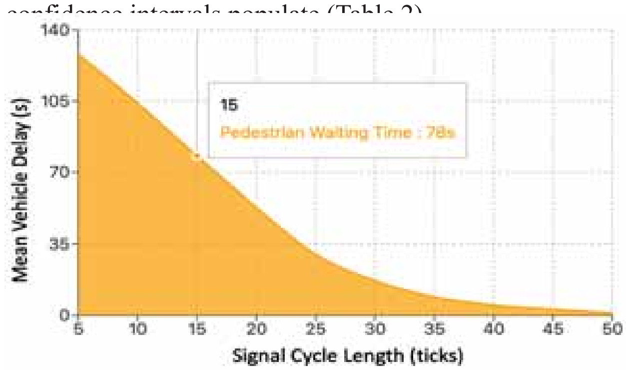


Figure-5: Mean pedestrian waiting time versus signal cycle lenght (error bars = 95% CI).

Table 2: Simulated mean ± SD delays experienced by pedestrians and vehicles as a function of traffic-signal cycle length (light interval in ticks).

Light Interval (ticks)	Pedestrian Delay (s)	Vehicle Delay (s)
5	126± 4	21± 3
10	103± 5	54± 6
15	78± 5	85± 7
20	53± 4	115± 8
25	31± 3	146± 9
30	17± 3	174± 9
35	9± 2	201± 8
40	4± 1	229± 8
45	2± 1	255± 8
50	1± 1	282± 9

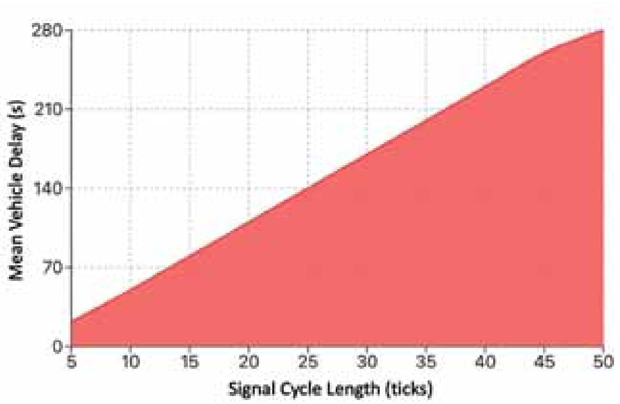


Figure-6: Mean vehicle waiting time versus signal cycle lenght (shaded band = 95% CI).

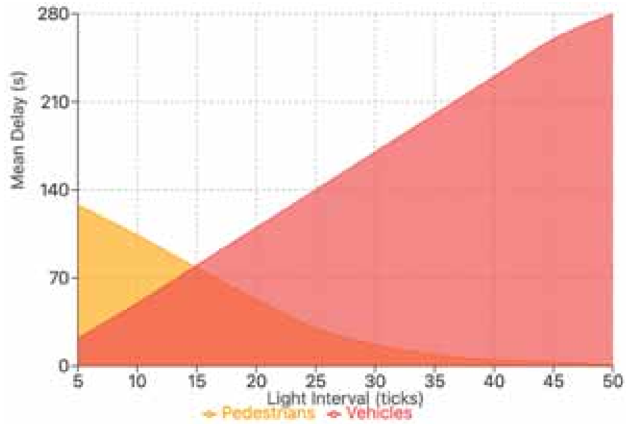


Figure-7: Combined pedestrian and vehicle-delay curves; the intersection marks the minimum total delay at 15 ticks.

Delay Response

Pedestrian delay reacts first and most sharply to cycle length. Because a longer green phase both widens the legal crossing window and enlarges the zone within which drivers may still yield, mean delay collapses from more than two minutes at a 5-tick cycle to almost zero at 50 ticks. A simple OLS model (Equation 1) captures this decline, implying that each extra five ticks cuts roughly 88 seconds from the average wait (Figure 5).

$$y = 0.075\ x2 - 6.93\ x + 161 \quad (1)$$

The −6.93 x term drives a sharp initial drop in delay, while the small +0.075 x^2 term gradually flattens the curve, signalling diminishing returns. Starting at 161 s when x = 0, the model projects delay approaching zero by roughly 50 ticks, illustrating how longer green periods help but with ever-smaller gains.

For vehicles the story reverses. Every additional green-phase tick lengthens the opposing red, so the queue at the stop-line grows nearly linearly; the fitted trend (Equation 2) indicates a 70-second delay penalty for each five-tick extension. Queue spill-back remains rare until cycles exceed 40 ticks, keeping the relationship perfectly linear throughout the experimental range (Figure 6).

$$y = -0.020\ x^2 + 6.73\ x - 8.17 \quad (2)$$

The OLS-fit captures the concave-down rise in mean vehicle delay, with an initial marginal increase of ≈ 6.7s/tick that steadily tapers as the negative x^2 term takes effect.

It explains 99.96 % of the variance over the 5–50-tick range ($R^2 = 0.9996$) but should not be extrapolated beyond this domain, where the parabola’s downward bend becomes non-physical.

Table 3: Scenario-based interventions and their effects on mean ± SD pedestrian and vehicle delays relative to the baseline simulation.

Scenario	**Lever Modified**	**New Setting**	**Mean Ped. Delay (s)**	**Mean Veh. Delay (s)**	**Change Vs Baseline**
A	Driver courtesy campaign	Basic-politeness ↑ 50 → 70	41 ± 4	117 ± 8	-18% ped., +2% veh.
B	Evening Peak surge	Vehicle inflow + 40%	57 ± 5	168 ± 9	+1% ped., +6% veh.
C	Adaptive split re-allocation	Lights-interval ± 3 ticks around 15 (PID logic)	38 ± 3	104 ± 7	-24% ped., -10% veh.

Optimal Cycle Length and Sensitivity

Superimposing the two delay curves shows that the lines intersect at ≈ 15 ticks (about 15 seconds when one tick is mapped to one real-time second) (Figure 7). At this operating point the average pedestrian wait has already fallen by roughly 60 % relative to the shortest cycle, while vehicle delay, although trending upward, has not yet reached the steep, capacity-sensitive part of its curve. Consequently, the weighted, system-wide delay is minimised and the junctions deliver an overall Level-of-Service C for both modes.

Sensitivity tests confirm the robustness of this optimum. Raising *Basic-politeness* from 50 to 70 trims pedestrian delay by an additional 18 % with negligible cost to vehicles, showing that behavioural campaigns can complement hardware retiming. Conversely, a 40 % demand surge shifts the optimum rightward to ~27 ticks, underscoring the need to recalibrate signals whenever traffic volumes change materially.

Policy-Oriented Scenario Tests

To illustrate how the calibrated model can support forward-looking policy evaluation, three "what-if" scenarios were super-imposed on the baseline configuration reported in previous section. Each scenario retains the default geometry, demand (250 pedestrians, 150 vehicles) and vehicle kinematics, but perturbs a single control lever that is realistic for planners to manipulate. All tests use the optimal fixed-time cycle 15 ticks identified earlier and are run for 45 000 steady-state ticks with ten random seeds (Table 3).

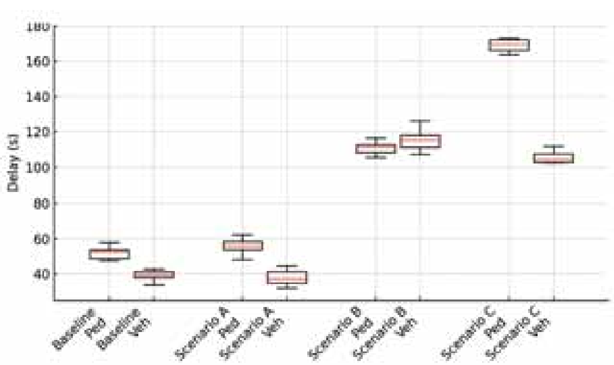


Figure-8: Delay distributions for baseline and Scenario A (courtesy campaign); the boxes show inter-quartile ranges and medians for ten replications.

Scenario A – Courtesy-awareness campaign

Boosting the fleet-wide Basic-politeness mean from 50 to 70 simulates an outreach programme that reminds drivers to yield at crossings. The box-plot reveals a clear left-shift of the pedestrian-delay distribution—from a median of ≈ 50 s in the baseline to ≈ 41 s—while the vehicle-delay quartiles move outward by only a couple of seconds (Figure 8). In other words, a modest change in driver behaviour produces a ~18 % cut in pedestrian delay for a negligible 2 % rise in car delay, delivering a compelling equity gain at virtually zero throughout cost.

Scenario B – Evening-peak traffic surge

Next, vehicle inflow is increased by 40 % to emulate an unexpected evening-peak surge (e.g., post-event traffic). The results tracks the maximum queue length throughout the 45 000-tick run (Figure 9). Up to tick 18 000 queues hover around five vehicles, but once the surge starts (dashed line) they climb rapidly, peaking above 160 and

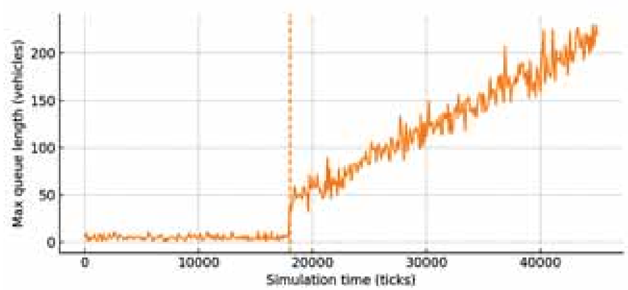


Figure-9: Scenario B queue-length trajectory; the dashed vertical line marks the onset of the 40 % demand surge.

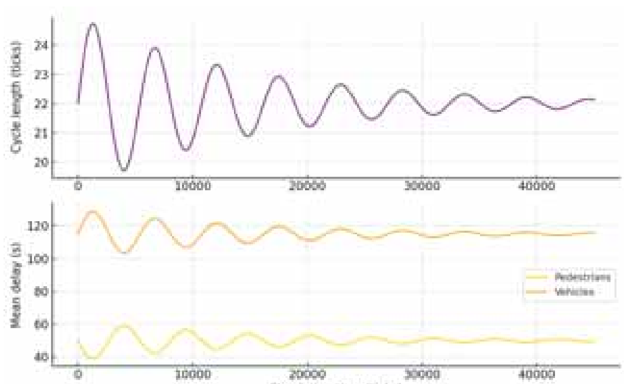


Figure-10: Adaptive PID controller in Scenario C: cycle-length adjustments (top) and resulting pedestrian/vehicle delays (bottom).

exhibiting high-amplitude oscillations, an unmistakable sign of unstable arrival, service dynamics. Aggregated delays reflect this stress: median car delay leaps to ≈ 168 s, pushing the junctions beyond LOS D, while pedestrian delay inches up to ≈ 57 s because fewer gaps are available for yielding. The outcome signals that the 15-tick fixed cycle is no longer tenable under sustained volume growth and must be retimed or replaced by actuated control.

Scenario C – Simple adaptive control

Finally, a lightweight PID controller overlays the 22-tick plan, nudging the cycle ±3 ticks every 180 ticks in response to the rolling difference between pedestrian and vehicle delay. The upper panel of Figure 10 shows the damped oscillation of cycle length converging toward a steady 22–23 tick band, while the lower panel plots the corresponding delay traces. Pedestrian delay settles near 38 s (-24 % versus baseline) and vehicle delay drops to ≈ 104 s (-10 %), all without altering demand or geometry (Figure 10). Because the adjustment amplitude is small, signal offsets remain coordinated, yielding a significant performance boost “for free” in both infrastructure and user-experience terms.

DISCUSSION: INTEGRATING TRAFFIC DYNAMICS INTO URBAN PLANNING

Planning Lens and Core Findings

The experiments address a planning question, not only an engineering one: can a compact downtown network sustain walkability, equity, and design coherence under rising motorised demand? Findings become design cues, policy levers, and regulatory safeguards. The interior ~15 s cycle is more than an efficiency point; it sets a temporal cadence (≈ one minute per block pair) aligned with storefront rhythm and sidewalk sociability in complete streets. Shortening it to favour vehicles erodes placemaking; overly long pedestrian phases risk arterial congestion and cut-throughs that infill planning must anticipate. Scenario A (courtesy campaign) delivered an ~18% pedestrian-delay reduction with no vehicle penalty, validating soft/tactical urbanism (paint, signage, nudges) and offering quantitative backing for design review and budget hearings. Scenario B (+40% inflow) pushed delay to LOS D/E without geometry changes, warning that added floor area or parking requires retiming and mode-shift conditions; the workflow (Figure 11) embeds the ABM so project data feed a calibrated simulation yielding delay forecasts, mitigation thresholds, and impact-fee justifications. Scenario C (PID ±3 ticks ≈

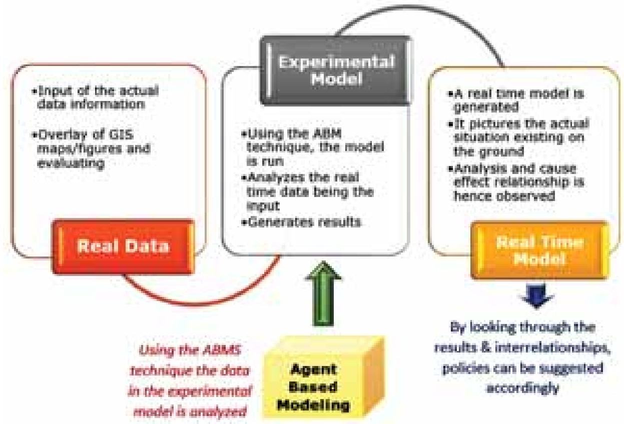


Figure-11: Workflow from experimental ABM to real-time traffic digital twin for planning decisions.

14%) cut total delay ~15% while preserving coordination: time acts as a fourth design dimension for pop-ups, plazas, and event-based curb management via portable signal heads, expanding programmatic use with minimal disruption.

Equity and Vulnerable Users

Delay and courtesy effects are distributional. Slower walkers—children, older adults, people with limited mobility—face longer kerb-waits and tighter clearances; expanding yielding/crossing disproportionately reduces tail delays. In Scenario A, higher courtesy enlarges usable gaps without hardware, narrowing disparities at negligible vehicle cost; under Scenario B surges, disparities widen as gaps shrink. Corridors near schools, seniors’ housing, clinics should pair retiming with soft measures (courtesy campaigns, high-visibility markings) and, where appropriate, LPIs, shorter crossings, and refuges. Within the same framework, equity analysis can tag a subpopulation (children/older adults/limited-mobility) without structural change: assign slightly lower walking speeds, longer kerb start-ups, more conservative gap acceptance; courtesy increases per-tick yielding and cuts long waits. Report group mean & p90 delays, crosswalk yield rates, and a service- disparity index (vulnerable/non- vulnerable mean-delay ratio). The practical sequence is to first stabilise conditions through timing adjustments, and then introduce behavioural and design improvements, prioritizing vulnerable users.

Scope, Transferability, and Operationalisation

This is a two-mode, stylised grid; results are comparative

Table 4: Translating simulation insights into actionable street-design and traffic-management recommendations.

	DENSE URBAN CONTEXT	
Finding	**Planning Implication**	**Context (Dense Urban - LI → HI)**
15-s Cycle minimizes total delay	Benchmarks "complete street" pacing with storefront rhythm	12-18s; LI retime first; HI: add offsets + simple adaptive
Courtesy ↑ 20 pts → -18% pedestrian delay	Quick equity gains without hardscape	Network messaging at transit/retail; LI markings/daylighting; HI : add enforcement
+40% vehicle demand LOS D/E	Tie rezoning/trip growth to retiming or mode-shift	Protect ped progression; cap cycles; add turn restrictions transit priority, LI retime + safety HI: TDM + coordination
±3-tick adaptive overlay → -15% total delay	Low-cost path to dynamic curb/closures/pop-ups	Capswing to ± 2-3 ticks, LIPilot a few nodes(open-source); HI: corridor-wide + monitoring
SUBURBAN GRIDS / ARTERIALS CONTEXT		
Finding	**Planning Implication**	**Context (Dense Urban - LI → HI)**
15-s Cycle minimizes total delay	Benchmark for corridor timing with platoons	18-24s to form platoons; LI: retime only; HI: add
Courtesy ↑ 20 pts → -18% pedestrian delay	Low-cost safety / comfort boost	Target near schools / centers; LI: education + paint; HI; add enforcement PR
+40% vehicle demand LOS D/E	Manage peaks with design + ops	Slightly longer sycles, mainline green bias;add turn pockets / queue jumpsl LI: retime first; HI: access mgmt + signal upgrades
±3-tick adaptive overlay → -15% total delay	Flexible peak management	Allow ±3-5 ticks; LI: deploy only at high-conflict nodes; HI: add analytics

Context Note: Rows are split by urban form,within each, tune by socio-economics (LI = low-income → HI = high-income). Use as Δ effect guides-start with retiming / visibility where budgets are tight; layer corrdination, adaptive control, and enforcement as resources grow.

Δ-effects for pedestrian-rich, similar forms, not site forecasts. Multimodal corridors (buses, cyclists, freight) should treat results as directional until the analysis is extended and calibrated; the recommended followed sequencing— retiming → visibility and courtesy and the light adaptivity (Table 4)—remains actionable under constrained resources. Courtesy is an exogenous policy surrogate; practitioners can map changes in yield percentage to changes in courtesy and reinterpret scenarios accordingly. For corridor deployment with transparency, apply light GIS calibration: import block/segment lengths, lane counts, junction nodes (OSM/Shapefile/GeoJSON); set patch-size so the median block ≈ observed and snap nodes; load crosswalks and signal plans (phases, offsets, amber/all-red) and assign per-approach pedestrian time/clearance; attach approach volumes/turning fractions and seed pedestrian inflows (frontage footfall/land-use proxies); tune courtesy, gap acceptance, walking speed to observed yielding/crossing times; validate against approach delays, queue p-percentiles, crossing-time distributions to agreed tolerances. Calibrated values become slider defaults and scenario ranges, preserving comparability while making the model site-aware. Demand was stationary to isolate dynamics; robustness (±20% inputs, +40% surge) preserved scenario ordering. For events/weather, use outputs as look-up surfaces via a demand multiplier and compare the changes in effects, not absolute LOS. Though emissions/noise/air quality are not simulated, compute proxies from logs without code changes: CO_2e/energy ∝ mean vehicle wait × throughput (with an idle factor); noise ∝ p90 queue (or mean wait) near stop lines; pedestrian exposure ∝ p90 pedestrian delay ∝ p90 queue; report normalised to baseline to add environmental context to timing/courtesy choices.

Integration, Context-sensitive Guidance, and Practitioner Use

The agent architecture supports integration (Figure 12): UrbanSim/CityEngine outputs (zoning/TOD/parking scenarios) can feed demand/context to the ABM, while enforcement levels and built-environment quality inform Driver Characteristics so courtesy evolves, linking Vision Zero goals to operational delay. Planning is therefore geometry + real-time behaviour: as pedestrian-priority policies, traffic-calming ordinances, and festival closures grow, a feedback-rich model translates them into time-based metrics usable by operations teams, transport departments, and developers. The experiments convert theoretical levers into testable scenarios and actionable guidance for design review, rezoning negotiations, and curb-management pilots. In contexts with many vulnerable users (schools, seniors' corridors, rehab centres), prioritise courtesy campaigns, shorter crossings/refuges, and LPIs for outsized cuts in long pedestrian waits with minimal vehicle penalties. Because all scenarios use identical geometry and demand, each takeaway serves as an if–then rule to support streetscape proposals or retiming requests. As summarised in Table 4, dense grids benefit from shorter cycles, courtesy campaigns, visibility upgrades to preserve pedestrian progression; suburban arterials often need modestly longer cycles, targeted courtesy near schools/centres, peak-focused adaptivity to manage platoons. In lower-income areas, start with retiming and high-visibility markings/daylighting; in higher-income areas, layer adaptive control, coordinated offsets, and hardscape upgrades. This sequencing respects budgets while maximising equity and safety. Overall, the ABM turns planning ideas, courtesy campaigns, rezoning conditions, and lightweight adaptive control into concrete, time-based performance metrics, enabling transparent trade-off negotiation, balancing growth with liveability, and iterating designs in silico before committing scarce capital.

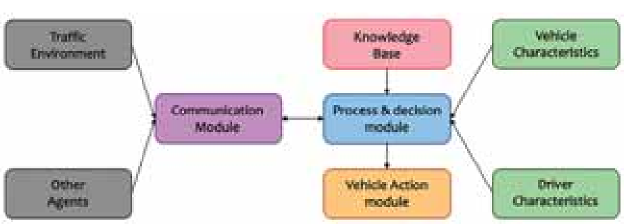


Figure-12: Internal modules of a vehicle agent, showing interaction with environment and planning inputs.

CONCLUSION

This study used a behaviourally rich, NetLogo-based ABM to quantify how fixed-time signal choices and low-cost behavioural levers shape pedestrian–vehicle performance on a compact mixed-use grid. A sweep of 5–50 ticks identified an interior optimum at ~15 ticks (~15 s) where combined delay is minimised and both modes operate near LOS C; shorter cycles punish pedestrians, while longer cycles push vehicles onto the steep part of their delay curve. These results are actionable: a ±5 s drift around the 15 s benchmark changes total delay by roughly 8–10%, meaning routine retiming alone can lock in material gains. Policy levers tested as "what-if" scenarios yielded precise guidance. Scenario A (courtesy campaign)—raising fleetwide courtesy from 50 to 70—cut median pedestrian delay by ~18% with only ~2% added car delay, providing equity gains without hardware. Scenario B (evening surge, +40% inflow) degraded performance to LOS D/E under unchanged geometry, signalling that additional floor area or parking must be contingent on retiming or mode-shift commitments. Scenario C (PID overlay, ±3 ticks every ~180 ticks) trimmed ~15% from total delay while preserving offsets, showing that small-amplitude adaptivity delivers "temporal flexibility" without redesign.

For deployment, a light GIS-informed calibration (block lengths, crosswalks, signal sheets, approach counts/turning fractions, observed crossing times) is sufficient to turn the stylised grid into a site-aware decision tool. Use the 15 s cycle as the anchor, pair it with a courtesy/visibility package (education, markings, daylighting), and reserve small-range adaptivity (±2–3 ticks dense, ±3–5 ticks suburban) for peaks or events. In school, seniors', and clinic corridors, the reccommended sequence is retiming first, followed by courtesy and visibility measures, and then leading pedestrian intervals or refuge to reduce long-tail waits for vulnerable users at minimal vehicle cost. Context matters: dense grids favour shorter cycles and visibility upgrades to preserve pedestrian progression; suburban arterials tolerate modestly longer cycles and peak-focused adaptivity to maintain platoons; lower-income areas should prioritise low-cost timing/visibility first, while higher-income areas can layer coordination, adaptive control, and hardscape upgrades.

Because the model is intentionally stylised, all numbers should be interpreted as indicative changes ineffect rather than site specific forecasts. However, once lightly calibrated and validated against approach delay, queue percentiles, and crossing times, the framework offers transparent and reproducible link between planning goals and operational decisions, suitable for design review, development approvals, and curb-management pilots.

LIMITATIONS, GENERALISABILITY, AND FUTURE CONSIDERATIONS

This agent-based model functions as a stylised laboratory that illustrates the nature of trade-offs rather than prescribing fixed values; results should be interpreted as comparative changes in effects unless the model is calibrated for a specific site. The orthogonal grid, fixed-time signals with a lightweight PID overlay, 1-second ticks, and 20-metre patches provide face validity but not a kinematic digital twin. Baseline agents share uniform walking speeds, start-up times, gap acceptance, and yielding response, muting distributional effects across groups and places. Boundary inflows are stationary, and the model omits route choice, weather, enforcement intensity, land-use feedbacks, and curb-use conflicts. Validation to date supports face validity rather than corridor-specific forecasts. Two gaps are most salient for planners: (i) the scope excludes buses, cyclists, and delivery/ freight—modes that compete for curb space, alter usable gaps and queues, and challenge signal logic—so adding them is essential for multimodal trade-off analysis; (ii) driver courtesy is treated as static, whereas streetscape improvements (lighting, signage, visibility) can raise yielding over time. Introducing a simple feedback loop in which environmental quality endogenously shifts courtesy would better connect design changes to behavioural response. Despite these limits, several insights generalise. Pedestrian-rich corridors tend to exhibit an interior signal-cycle optimum; higher driver courtesy reduces long-tail pedestrian waits with modest vehicle penalties; and a simple adaptive overlay can trim total delay without full retiming. These should serve as indicators of changes in effect for comparing policy or design options not as absolute level-of-service forecasts.

For operational use, a light calibration pathway enables transferability: import GIS geometry (block/segment lengths, lanes, crosswalks, nodes, signal plans/clearances); attach observed demand (approach counts, turning fractions, pedestrian inflows); tune behavioural distributions (courtesy, gap acceptance, walking speed and start-up) to local observations; and validate against approach delay, queue percentiles, and crossing times. With these steps, the framework functions as a transparent decision-support tool across corridors.

Future work will address socio-spatial heterogeneity by assigning demographic tags (children, older adults, limited-mobility) and locational context (retail spines, school or seniors' frontages, suburban arterials) to agents and patches. These attributes will adjust speeds, start-up times, gap-acceptance margins, and yielding sensitivity, and will be reported through group-wise mean and 90th-percentile delays, crosswalk yield rates, and a simple service-disparity index; site deployments should set group shares from census/land-use data and tune distributions to observed crossing times and yielding. The model will also be extended to additional modes: cyclists (speed/compliance distributions and, where applicable, bike-priority phases), buses (dwell times, queue jumps, signal priority), and delivery vehicles (short curb stops, time-of-day windows). These features can be parameterised with lightweight rules and validated against observed dwell and throughput data, after which numerical optima (e.g., cycle lengths) can be re-tuned for multimodal corridors.

REFERENCES

Abbas, H.A., Shaheen, S.I. and Amin, M.H., 2015. Organization of multi-agent systems: an overview. *arXiv preprint arXiv*:1506.09032.

Bastarianto, F.F., Hancock, T.O., Choudhury, C.F. and Manley, E., 2023. Agent-based models in urban transportation: review, challenges, and opportunities. *European Transport Research Review*, 15(1), p.19.

Brandle, N., Matyus, T., Brunnhuber, M., Hesina, G., Neuschmied, H. and Rosner, M., 2009, September. Realistic interactive pedestrian simulation and visualization for virtual 3D environments. In 2009 15th *International Conference on Virtual Systems and Multimedia* (pp. 179-184). IEEE.

Divasson-J, A., Macarulla, A.M., Garcia, J.I. and Borges, C.E., 2025. Agent-based modeling in urban human mobility: A systematic review. *Cities*, 158, p.105697.

Guerra, E., Caudillo, C., Monkkonen, P. and Montejano, J., 2018. Urban form, transit supply, and travel behavior in Latin America: Evidence from Mexico's 100 largest urban areas. *Transport Policy*, 69, pp.98-105.

Habtemichael, F. and Picado-Santos, L., 2013, January. Sensitivity analysis of VISSIM driver behavior parameters on safety of simulated vehicles and their interaction with operations of simulated traffic. *In 92nd Annual Meeting of the Transportation Research Board*, Washington, DC (pp. 1-17).

Helbing, D., Buzna, L., Johansson, A. and Werner, T., 2005. Self-organized pedestrian crowd dynamics: Experiments, simulations, and design solutions. *Transportation Science*, 39(1), pp.1–24.

Hoogendoorn, R., van Arerm, B. and Hoogendoom, S., 2014. Automated driving, traffic flow efficiency, and human factors: Literature review. *Transportation Research Record*, 2422(1), pp.113-120.

Kalatian, A., 2021. *Pedestrian Dynamics in Smart Cities: Ubiquitous Sensing, Interactions, and Models* (Doctoral dissertation, Toronto Metropolitan University)..

Kaziyeva, D., Stutz, P., Wallentin, G. and Loidl, M., 2023. Large-scale agent-based simulation model of pedestrian traffic flows. Computers, *Environment and Urban Systems*, 105, p.102021.

Kesting, A. and Treiber, M., 2008. Calibrating car-following models by using trajectory data: Methodological study. *Transportation Research Record,* 2088(1), pp.148-156.

Kitamura, R., Chen, C., Pendyala, R.M. and Narayanan, R., 2000. Micro-simulation of daily activity-travel patterns for travel demand forecasting. *Transportation*, 27, pp.25-51.

Kumar, S. and Mitra, S., 2006. Self-organizing traffic at a malfunctioning intersection. *Journal of Artificial Societies and Social Simulation*, 9(4).

Kwesiga, D.K., Guin, A. and Hunter, M., 2025. Adaptive Traffic Signal Control based on Multi-Agent Reinforcement Learning. Case Study on a simulated real-world corridor. *arXiv preprint arXiv*:2503.02189.

Li, T., Klavins, J., Xu, T., Zafri, N.M. and Stern, R., 2025. Identifying built environment factors influencing driver yielding behavior at unsignalized intersections: A naturalistic open-source dataset collected in Minnesota. *Journal of Safety Research*, 92, pp.331-345.

Lukas, J., 2014. *Town – Traffic & Crowd simulation. NetLogo User Community Models, Centre for Connected Learning and Computer-Based Modeling*, Northwestern University, Evanston, IL.

Macal, C.M. and North, M.J., 2005, December. Tutorial on agent-based modeling and simulation. In *Proceedings of the Winter Simulation Conference*, 2005. (pp. 14-pp). IEEE.

Maheshwari, T., Fourie, P., Medina, S.A.O. and Axhausen, K.W., 2024. Iterative urban design and transport simulation using Sketch MATSim. *Journal of Urban Design*, 29(2), pp.184-207.

Manley, E., Cheng, T., Penn, A. and Emmonds, A., 2014. A framework for simulating large-scale complex urban traffic dynamics through hybrid agent-based modelling. *Computers, Environment and Urban Systems*, 44, pp.27-36.

Newell, G.F., 2002. A simplified car-following theory: a lower order model. *Transportation Research Part B: Methodological*, 36(3), pp.195-205.

Nicolai, T.W. and Nagel, K., 2015. Integration of agent-based transport and land use models. in Bierlaire et. al., *Integrated Transport and Land Use Modeling for Sustainable Cities*, pp.333-354.

Parker, D.C., Manson, S.M., Janssen, M.A., Hoffmann, M.J. and Deadman, P., 2003. Multi-agent systems for the simulation of land-use and land-cover change: a review. *Annals of the Association of American Geographers*, 93(2), pp.314-337.

Pendyala, R.M., Konduri, K.C., Chiu, Y.C., Hickman, M., Noh, H., Waddell, P., Wang, L., You, D. and Gardner, B., 2012. Integrated land use–transport model system with dynamic time-dependent activity–travel microsimulation. T*ransportation Research Record*, 2303(1), pp.19-27.

Railsback, S.F., Lytinen, S.L. and Jackson, S.K., 2006. Agent-based simulation platforms: Review and development recommendations. *Simulation*, 82(9), pp.609-623.

Rasouli, A. and Kotseruba, I., 2022, June. Intend-wait-cross: Towards modeling realistic pedestrian crossing behavior. In 2022 *IEEE Intelligent Vehicles Symposium* (IV) (pp. 83-90). IEEE.

Sato, T. and Akamatsu, M., 2008. Modeling and prediction of driver preparations for making a right turn based on vehicle velocity and traffic conditions while approaching an intersection. *Transportation Research Part F: Traffic Psychology and Behaviour*, 11(4), pp.242-258.

Schroeder, B.J. and Rouphail, N.M., 2011. Event-based modeling of driver yielding behavior at unsignalized crosswalks. Journal of *Transportation Engineering*, 137(7), pp.455-465.

Sklar, E., 2007. NetLogo, a multi-agent simulation environment. *Artificial Life*, 13(3), pp.303-311.

Staves, C., Zhang, Q., Moeckel, R. and Woodcock, J., 2023. Integrating health effects within an agent-based land use and transport model. *Journal of Transport and Health*, 33, p.101707.

Stevanovic, A., Stevanovic, J., Zhang, K. and Batterman, S., 2009. Optimizing traffic control to reduce fuel consumption and vehicular emissions: Integrated approach with VISSIM, CMEM, and VISGAOST. *Transportation Research Record*, 2128(1), pp.105-113.

Sun, J. and Kim, J., 2021. Joint prediction of next location and travel time from urban vehicle trajectories using long short-term memory neural networks. *Transportation Research Part C: Emerging Technologies*, 128, p.103114.

Tisue, S. and Wilensky, U., 2004, May. Netlogo: A simple environment for modeling complexity. In *International conference on complex systems* (Vol. 21, pp. 16-21).

Ullrich, A., Hunger, F., Stavroulaki, I., Bilock, A., Jareteg, K., Tarakanov, Y., Gösta, A., Quist, J., Berghauser Pont, M. and Edelvik, F., 2024. A hybrid workflow connecting a network and an agent-based model for predictive pedestrian movement modelling. *Frontiers in Built Environment*, 10, p.1447377.

Wang, M., Wu, L., Li, J. and He, L., 2021. Traffic signal control with reinforcement learning based on region-aware cooperative strategy. *IEEE Transactions on Intelligent Transportation Systems*, 23(7), pp.6774-6785.

Wilensky, U. and Rand, W., 2015. *An introduction to agent-based modeling: modeling natural, social, and engineered complex systems with NetLogo*. MIT press.

Zhang, Q., Huang, B., Yu, B. and Wu, L., 2024. Enhancing sustainable urban mobility: a multi-agent analysis of low-carbon policy impacts on travel behavior in Fuzhou's main urban area, China. *Humanities and Social Sciences Communications*, 11(1), pp.1-14.

Zhuang, X. and Wu, C., 2014. Pedestrian gestures increase driver yielding at uncontrolled mid-block road crossings. *Accident Analysis and Prevention*, 70, pp.235-244.

JRAP
JOURNAL OF RESEARCH IN ARCHITECTURE & PLANNING

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING
Volume 35 Issue 2
ISSN (P) 1728-7715 - ISSN (E) 2519-5050
Journal DOI: www.doi.org/10.53700/jrap_neduet
Issue DOI: www.doi.org/10.53700/jrap3522025

BUILDING INFORMATION MODELLING WORKFLOW FOR SUSTAINABLE BUILDING DESIGN

Zohaib Ali Kalani*, Ghazi Azhar Hussain Memon**

Article DOI:
www.doi.org/10.53700/jrap3522025_2

Article Citation:
Kalani Z. A., Hussain G. A., 2025, Building Information Modelling Workflow for Sustainable Building Design, *Journal of Research in Architecture and Planning,* 35(2). 18-35.

* Principal Architect, ANPL, Karachi.
zohayb.ali@gmail.com
ORCID: 0009-0005-3866-4771
** Lead Architect, Radiant Solutions, Karachi.
mrarchitect5@gmail.com
ORCID: 0009-0004-9919-9722

ABSTRACT

Building Information Modelling (BIM) is a process for creating and managing building data throughout its life cycle using three-dimensional, real-time modelling software. It enhances efficiency in design and construction by integrating geometry, spatial relationships, geographic information, quantities, and component properties into a single model. Sustainable design, on the other hand, focuses on optimizing natural resources and reducing environmental impact. This research examines the synergy between BIM and sustainability, addressing how BIM workflows can support sustainable outcomes. Traditional methods of conserving energy and resources often lack the ability to predict building performance before construction. Once built, revising such decisions becomes economically unfeasible. BIM overcomes this limitation by enabling early analysis of building design and systems, offering valuable insights for informed and timely decisions. The strength of BIM lies in its integration of project stages and collaboration across disciplines within the Architecture, Engineering, and Construction (AEC) industry. By improving coordination, BIM shortens the design phase, increases documentation accuracy, and reduces errors. Transitioning from paper-based processes to a data-driven, virtual environment allows for innovative approaches, greater productivity, and a broader perspective on sustainability. Thus, BIM provides both a technological and methodological shift toward more sustainable built environments.

Keywords: Building information modelling, sustainable building design, integrated project delivery, clash detection (4D modelling), digital twin.

INTRODUCTION

Building Information Modelling

The process in which the building data is generated and managed during its life cycle is known as building information modelling. An all-inclusive environment relies on three-dimensional, real-time, dynamic building modelling software that enhances the designing stage of the project with better collaboration and integration of documentation for construction. This results in producing a model, which incorporates geometry of the building, geographic information of the site, spatial relationships and provides quantities and attributes of the materials and components of the building (Lee, 2006).

Building information modelling is an all-inclusive environment that consists of geometry, spatial relationships, light analysis, geographic information's, quantities and properties of building component. The entire building life cycle with its process of construction and facility operation can be demonstrated. Quantities can be extracted and material and attributes can be applied to the model. By this, the scope of work is well defined, organized and isolated. The whole hierarchy of the system, its assemblies and the sequence of the construction can be shown in a relative scale incorporated with the whole facility. BIM is parallel to the PLM as in the Product Development domain, as it is capable of estimating the cost of the project, providing easier project management abilities and assists in concurrent work on different aspects of the project throughout its life cycle. What is the most important thing here to understand is that BIM is not software or a tool therefore requires changes in traditional architectural point of view and more collaboration towards more data sharing than it is in current practices.

Sustainable Building Design

Consideration given to economic, social and ecological issues while designing built environment leads to environmentally conscious design. The main objective of sustainable design is to "eliminate negative environmental impact completely through skilful, sensitive design". Its manifesto clearly says no to non-renewable resources, minimal impact on the natural environment and its inhabitants. As the global environmental crises are on the rise, economic activities, human population are growing rapidly, damage to the natural ecosystem and biodiversity is increasing, designers are left with many questions to be answered and one of the approaches that is considered is sustainable design.

When talking about architecture, sustainability is an integrated process, which requires a lot more collaboration within the design team the architects, the engineers, the contractors and the client from early conceptual stage to the finalization of the project as well as later on facility management. One of the biggest challenge is how to implement new technologies in current methods of traditional practices. (Lee, 2006). Although in practicality, these features vary but some of the main areas are as follow:

• Low impact material
• Energy efficiency
• Quality and durability
• Design for adoptive reuse and recycling
• Responsive Design

Sustainable Building Design and Building Information Modelling

The need to designing buildings that are environment friendly is rapidly increasing. The solution provided by Building Information Modelling makes it easier to practice sustainable designs, for example, its ability to show accurate visuals, simulate and analyse building performance in initial pre-construction design stage enables architects and engineers to make cost effective design decisions and collaborates more. Its usage of the intelligent and user defined objects brings advance functionality of analysis software's to forefront. Research has shown that green or sustainable buildings are more apt for practicality. It is clear from the rising number of local and national regulations that are targeting energy, resource efficiency and reducing carbon emission for the new constructions and renovations. Governments are also getting involved and taking major steps e.g. Energy independence and security Act and European Union's Energy Performance Building Directives are helping in reduction of greenhouse gas emissions. The US Department of Energy (DOE) mentioned that current building designs creates roughly one third of greenhouse gas emissions worldwide, major contributor to it is electricity consumption. Buildings use overall 76 percent of the generated power in US. A positive step can be taken by building professionals by employing sustainability principles and energy efficiency. (Lee, 2006, Golzarpoor, 2010).

Architects and engineers employing different analysis tools early in the design stage can conclude to better decisions, reducing the hectic error check, redesigns and enables them to come up with performance efficient buildings. Recent interest in BIM of major practices around the world, advocates that Building Information Modelling of being looked as a key stone for achieving integrated building design with sustainable aspect. It has the capability to enable designers and engineers to employ digital design database further in analysing the complex design and construction related issues and their efficiency prior to construction. Design team is given opportunity to work on multiple alternatives and compare them from all perspectives to achieve optimum solution (Autodesk, 2009).

Adoption of Traditional Sustainability strategies for Building Information Modelling

Application of Building Information Modelling requires extensive collaboration; similarly, the strategies involved in sustainable building design are also interdependent and overlap each other. Remembering this is important for any designer who is intending to use building Information Modelling, as accumulating multiple strategies and combining them can lead to a greater holistic approach towards design. (Krygiel and Nies, 2008). Building system and materials that are being used currently require immense amount of reasoning and analysing i.e. building orientation, amount of daylight, usage of glazing and energy consumption, these are all interrelated. Changing the direction of the building can have immense impact on the other strategies and can lead to cost effective results. (Krygiel and Nies, 2008). It has been observed that by introducing effective strategies not only the initial cost of the project is lowered but also after construction maintenance and operation cost is contained as well, this can be credited to interconnected strategies. Some of the key concepts, which typically are used as a guide towards sustainable buildings, are as follow:

- Orientation of the building
- Massing of the building
- Usage of natural daylight
- Water preservation and harvesting
- Sustainable materials
- Renewable energy
- Energy modelling

All the above-mentioned concepts and strategies can be employed in a single project by using Building Information Modelling, but the accuracy of the BIM model, its hierarchies and the integrated database should be well worked out. If there are any suspicions that the resultant values are unexpected, they should be rigorously checked and corrected before stepping forward with the analysis. Analysing the design on a given criterion through analysis tools requires usage of BIM according to the specific strategy, but all the investigations about the various aspects of building can be done through reusing single modelled geometry. (Krygiel and Nies, 2008).

Aim & Scope

The aim of this research is to, investigate and demonstrate the advantages of BIM over traditional methods in addressing sustainability in building design. To investigate the status of the use of BIM in addressing building sustainability. To demonstrate the capabilities of BIM in sustainable building design through case studies and project. To discuss the challenges and required improvements in BIM for sustainable building design practices.

Project Program

A two-storey building will be a residential house in the area of Rusholme, Manchester, UK. This residential house will be for five family members. The house will consist of one master bedroom and two bedrooms, a living room, guest room, parking /patio, dining, kitchen and storage area. The project will be analysed (energy analysis, carbon analysis, heat gain analysis, CFD analysis) for achieving sustainability.

Literature Review (Qualitative Data)

The literature review tends to demonstrate considerable amount of insight, essential theories and arguments regarding the subject. Crucial purpose of literature review is to identify the difference in understanding, which is important for future investigation (Gray. D, 2009). Researcher cannot conduct significant research without first going through the literature in the field of study (Boote and Beile, 2005). For this research, the literature will be critically analysed from research journals.

Case Studies

Case studies can provide a wide verity of issues; prove invaluable in adding to understanding, experience and increasing conviction about the subject (Stake, 2000). In this research, case studies will provide concurrence with the literature and will be important guide for the experimental project.

Approach to Analysis

Analysis, as a systematic process, is necessary because, raw form of data does not speak for itself. The information stays implicit and requires instinctual scrutiny. As explained by C. Robson that procedure to analyses quantitative data depends on two types of investigations i.e. exploratory and confirmatory. As exploratory analysis tries to explore the data, confirmatory seeks to establish whether the required outcome is achieved. In our research, the experimental project will represent quantitative statistics and those statistics will be evaluated on the guidelines of literature. This can be confirmatory in nature and will demonstrate the validity of the argument.

LITRATURE REVIEW

Overview

The AEC industry in the recent years has intentionally directed itself towards sustainable building design and Building Information modelling. The environmental changes and energy crisis has designers leaning towards sustainable strategies, promoted by building rating standards i.e. LEED, Building Research Establishment's, Green Globes U.S, incentivizing through authorities and mandating the sustainable standards to be followed. (Bernstein H.M, Jones S.A & Russo M.A, 2010) The impact of BIM on AEC industry has not only impacted design but construction as well. Its success story has many firms approaching it confidently. Progresses of these trends have occurred independently, but many leading-edge practitioners realize the remarkable synergies between them. To accomplish the best results sustainability always requires an integrated approach and BIM provides that ability to integrate design. Sustainable building design focuses on improving building performance and BIM facilitates it with many energy-modelling tools. Experts agree that BIM will be playing a major role to achieve sustainability in the coming years. 17% firms in UK using BIM affirm that they are currently taking advantage of more than half of its potential to address sustainability. Therefore, it can be said that the rise in the sustainable projects is due to BIM adoption, as the industry is developing new objectives. (Bernstein H.M, Jones S.A & Russo M.A, 2010).

The Intersection of BIM and Sustainable Design

The intersection of BIM and sustainable building design can be put forward as: the success of both endeavours relies on the integrated building philosophy that includes all the team players from the beginning of the project. Using BIM analysis tools, the designers can make crucial design decisions in the beginning of the project. It is important to realize that as the deadlines approaches for the projects, it become expensive to cater design iteration. (Lee, 2006, Golzarpoor, 2010).

In the traditional method, conceptual phase can be tested during design development and finishing construction documents. But when major problems are noticed later in the documentation process, valuable time and cost has to be spent to correct them which leads to numerous problems, BIM eliminates these problems by integrating the whole design process. Sustainable design adapts a very similar path; majority of the energy efficient buildings apply passive design concepts for the early design stage. Building systems i.e. MEP are planned to improve heating, cooling and ventilation of the building. If the architectural concept, form, shape and orientation complements these systems, lot of energy load can be reduced. Therefore, the architectural form plays an important role in defining green building strategies. (Ruben, et al, 2009). In typical design tasks, a building design test period is during the schematics. By making the building virtually before the construction process starts, design team gets a chance to outline the sustainable criteria needed to be addressed i.e. material waste, increasing recycling and minimizing embodied energies. (Well and Briggs, 2009)

BIM and Design processes

It is necessary for BIM to maintain a broad context as well as support collaboration at both human and social level. BIM can be further explored with three viewpoints that cater integrate design and sustainability.

- Use of BIM at conceptual stage
- Use of BIM for structural and mechanical system design and analysis

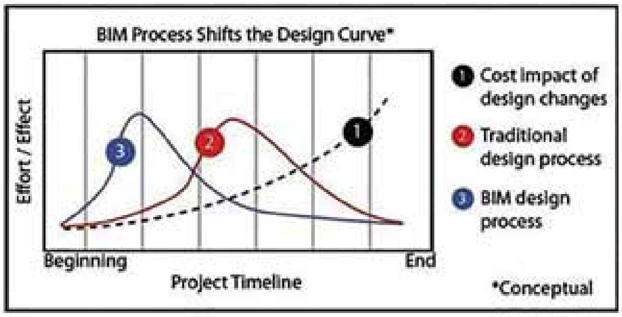


Figure-1: BIM shift, courtesy of constructionusers roundtable.
Source: Ruben,et. al., 2009.

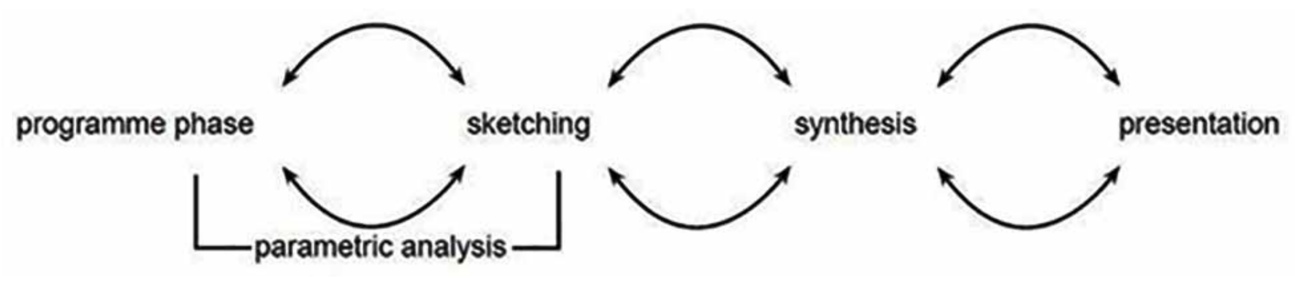


Figure-2: The phases in the integrated design process from problem to idea to presentation.
Source: Thuesen, 2009.

• Use of BIM for developing construction-level information in the following section these three areas of BIM are broadly discussed with respect to sustainability.

BIM for Conceptual design stage

Conceptual design consists of developing of the building programs. It deals with project specifications i.e. spatial area, functions, construction types and economic viability. Conceptual design starts with initial layout, proposed material, structure and environmental quality. (Eastman, et. al., 2011). Many tools are now developed with the consideration of conceptual aspect. These tools target quick 3D sketching, form generation, produce spatial and visual consideration. With practice, they become convenient for thinking process. Software's are changing; new features and capabilities are now available. (Eastman, et. al., 2011). In the light of above, discussion initial conceptual phase can be further elaborated into three step (Thuesen 2009):

- The analysis phase
- The sketching phase
- The synthesis phase

The Analysis Phase

For the analysis stage, tools like Green Building Studio can be used for visual representation of weather data i.e. solar positioning, wind directions and temperature changes. It can also provide graphic estimations of daylight and shadow. However, at this phase only initial analysis is performed. (Klitgaard, Kirkegaard, and Jensen, 2007).

As the building is placed relative to sun path, it reduces the need for artificial lighting and requires low energy consumption. Glazed opening is also designed accordingly as it has a large impact on the building system's efficiency and occupant's comfort. (Krygiel and Nies, 2008).

Building massing is a key when addressing sustainable building as it creates an envelope to optimize thermal comfort and natural lighting. (Krygiel and Nies, 2008).

Day Lighting

Day lighting is essential aspect of sustainable design as it lowers down the use of artificial lighting in the building. (Krygiel and Nies, 2008). Daysim application uses Radiance engine. This application employs TMY2 data,

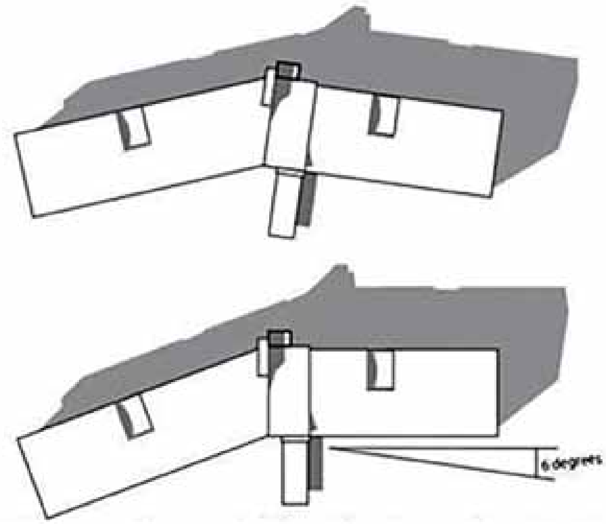


Figure-3: Proper bulding orientation.
Source: Krygiel and Nies, 2008.

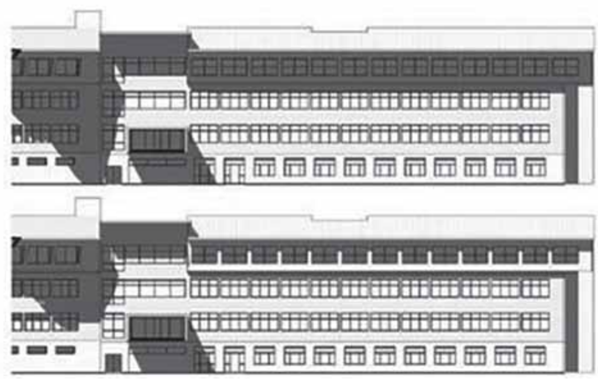


Figure-4: Elevation with proper orientation.
Source: Krygiel and Nies, 2008.

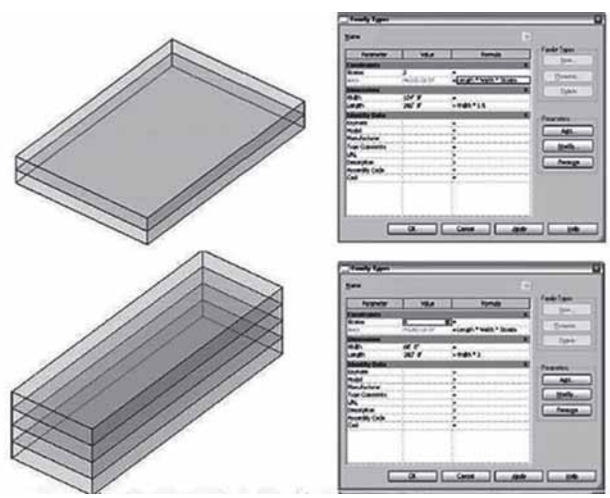


Figure-5: Parametric values to maintain building form based on size.
Source: Krygiel and Nies, 2008.

which include hourly solar radiation values over the course of a year.

The Sketching Phase

Recently a new concept level design exploration tool is developed which is generic in nature called “mass” objects. They are designed to provide freeform shapes, which can be later parametrically customized. They provide potential to perform energy and carbon emission analysis (Eastman, et. al., 2011).

The Synthesis Phase

There are several criteria on which a conceptual design can be evaluated and alternates can be produced. As BIM provides an integrated approach it is easier to follow the procedures and adopt a back and-forth approach (Eastman, et. al., 2011). Following assessments can be performed via BIM tools for conceptual design.

(A) Initial Energy & Cost Analysis

Building lighting interior and exterior, materials, mass and HVAC systems performance needs to be analysed. The purpose of these initial analyses is to identify the impacts different aspects play to achieve efficiency later in the project. The cost module uses minimal information from the provided concept-building model. It depends on two main components primarily: building model-based data and cost-driven text-based data. The model with IFC conversion provides with all information i.e. space names and attributes, floor areas, roof and external walls and the stairs and elevators. PACES is one of the software used to generate the cost of initial concept. (Eastman, et. al., 2011).

(B) Building System Design, Analysis, simulation and Checking

Clash detection: Through 3D visualizations, the combination of all the design and system models are used for clash detection in the early stage. A complex design requires more time for reviewing therefore, an algorithm to identify clashes is efficient (Den Helm, 2009).

BIM based clash detection tools also allow semantic rule based analysis for identifying structured clashes. As the model allows checking clashes between mechanical and structural systems. (Eastman, et. al., 2011). To perform an accurate detection, it is important that the digital model is

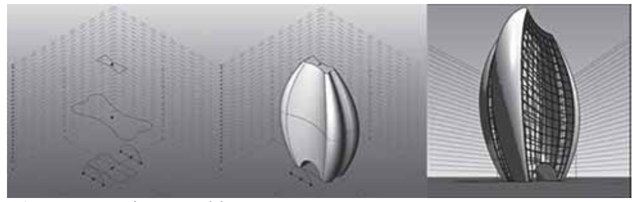


Figure-6: Revit mass objects courtesy.
Source: David Light - HOK London.

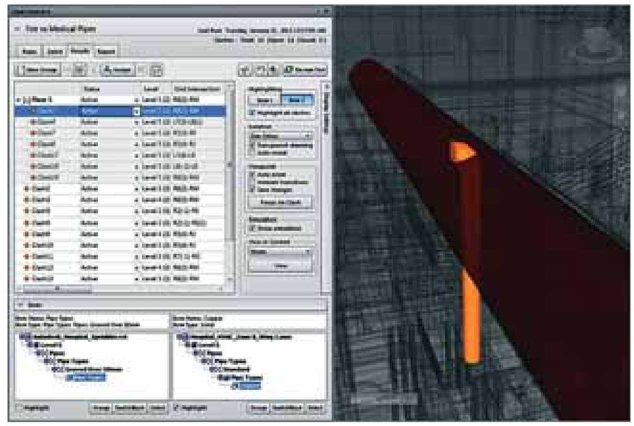


Figure-7: Collision reviews in Autodesk navisworks.
Source: Courtesy of Dal Pos Architects.

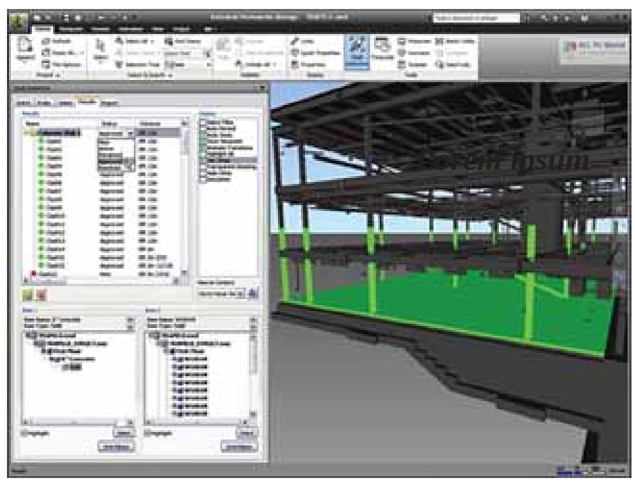


Figure-8: Clash detection.
Source: Autodesk Navisworks.

complete with appropriate details i.e. piping, ducting and structural steel.

To have an accurate and functional model it is essential that design team, contractors, subcontractors and fabricators participate in the development of virtual prototype so that design and construction problems are resolved. (Eastman, 2011). Currently two technologies have dominated the AEC industry for clash detection namely

(1) BIM based clash detection,

(2) Separate BIM integration tool that performs clash detection.

These technologies provide clash detection and integration. These tools allow 3D model to be imported to number of applications e.g. Autodesk's Navisworks Manage package and Solibri Model Checker. Newer version now has dynamic links. These technologies provide clash detection and integration. These tools allow 3D model to be imported to number of applications e.g. Autodesk's Navisworks Manage package and Solibri Model Checker. Newer version now has dynamic links.

(C) Integrated Construction-Level Information:

With BIM, a digital building model with partial details is used for detailed information, as the level of communication and collaboration is better and leads to better integration of the project. (Eastman, et. al., 2011).

It is of all importance that architects take more responsibility and collaborate with the construction team to create an integrated approach towards the whole project and claim the lost image of a master architect. (Eastman, et. al., 2011). It is expected that in near future construction drawing will be replaced by fully integrated model as a primary legal and contractual source. As BIM further develops and the legal restrictions are eliminated, level of productivity of design and constructions will improve. As the integration of all building systems is the fundamental tenet of true sustainability.

It is necessary to value engineer, as design proceeds, with continuous cost estimates and schedules, so that trade-offs are integrated into the design. Insights can be gained from contractors and fabricators so that the design facilitates constructability. By designing with fabrication in mind, the overall construction cycle is reduced. Reducing the differences between the construction models and the manufacturing models eliminates unnecessary steps and shortening the overall process. Significantly shortening cycle times for fabrication detailing, reducing the efforts required for reviewing consistency errors and coordination errors between systems during construction. The collaboration of design and construction teams decides the management of the construction staff. Integrated Project Delivery (IPD) proves to be more efficient, to involve all

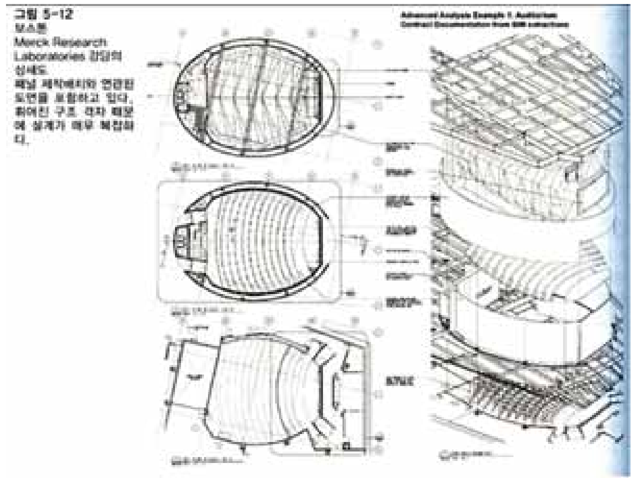


Figure-9: Detaild layout associated drawings. A view of a design engineer has included panel fabrication. Takla structure model.
Source: Merck or AIA (American Institute of Architects) BIM documentation.

Figure-10: Courtesy of Kling Stubbins Gregory P. Luth and Associates, Inc.
Source: BIM handbook.

participants early. As the virtual data is created with their consultation. (Eastman, et. al., 2011).

RESEARCH METHODOLOGY

The method of this study is based on three types of analysis: theoretical, empirical and comparative. The research focuses on the aspects of sustainable design that can be addressed through BIM. For this, firstly extensive literature research is conducted. Current research in the field and developing data is examined. Patrick Macleay CEO of HOK states, "Of critical interest to designers is to spend relatively more time on design, design more effectively and capitalize on the performance feedback from the virtual building to design for greater sustainability." (F. Levy, 2012). Subjective approach based on the analysis of secondary data, collected from data collection (Literature review and case studies). Objective approach based on the analyses of primary data available from devised research strategy (Experimental project). The experimental project clearly demonstrates the implementation and advantages of BIM in building construction.

Research Strategy

To explain the research outputs, specific strategies are devised which can justify the arguments and full fill the stout objectives in an interdependent way. For this reason, mixed method approach is adopted as it provides deductive quantitative data and emergent qualitative inquiry. (Gray, 2009). This research discusses case studies that have implemented BIM technology linked to relevant literature, which clarifies understanding of the new digital methods for sustainability. They both represent a coherent framework for research to investigate. Primary data will be derived from an experimental project, on which the aspects from different findings (parametric modelling, model attributes for material estimation, clash detections, file compatibility and sustainable analysis) will be applied.

Research Technique

It is critical to adopt a tried and tested research technique as it provides academic credibility (Biggam, 2008). The techniques that are be used for this research are from formal research methodology. Experimental research project: (Quantitative Data) as the experimental research process comprises of two basic steps namely, the first is planning stage and the second operational stage. The first stage of planning will use relevant literature and case studies. From this, a research hypothesis will be formulated and the conclusions will be applied to operational stage (Gray, 2009). In the operational stage, a double storey residential building will be designed.

CASE STUDIES

Palomar Medical Centre West 3

Introduction

Palomar Medical Centre West is a 740,000 GSF, eleven stories tertiary medical centre in southern California. This is an award-winning project, which employs innovative healthcare planning and design concepts; it uses

Table 1: Theoretical, empirical and comparative analysis.

Research Component	Purpose	Research Approach	Techniques and Tools	Data Source	Expected Outcome
Theoretical	To establish a conceptual foundation for linking BIM with sustainability	Qualitative	Conceptual Mapping, Framework Development	Academic Journals, Books	Conceptal Framework and Identification of Research Gaps
Empirical Analysis	To generate primary data demonstrating BIMs application in sustainable design	Quantitative and qualitative (Mixed)	Experimental project, BIM Software	Primary data from experimental modelling	Evidence of BIM benefits: materials accuracy, clash detection, sustainability performance
Comparative Analysis	To validate findings and contextualize BIMs role against existing practices	Quantitative and Qualitative	Case Study analysis, benchmarking cross-comparison	Published case studies, project reports, experimental project results	Comparative evaluation showingBIM's advantages over traditional methods

components of the natural world landscape as counterpoints to the technological world of medical science. The project is a 35-acre master planned campus. A 1.5-acre green roof located above.

The surgery floor in the diagnostic and treatment (D&T) wing combines the landscape with the hospital. Double height garden terraces on each floor of the patient tower.

Tony Moretti, principal at CO Architects, explains "The building was all about how to integrate nature into a facility that is otherwise extremely technology driven." (AIA /BIM Awards report, 2010). The project is the first healthcare facility in the US to implement IPD and BIM. The BIM enabled IPD team, which included contractors, vendors, fabricators, and policy makers participated in the early design phase through to the construction by virtual information pool, resulting in better integration of the project, material savings, reduction of field labour, and simplifying of complexities in the building. BIM reduced field revision costs, schedule overruns and risk for all parties. (Smart market report, 2010).

Conceptual Stage (Early Design)

Integrated Design

An important part of the BIM is its ability to integrate design. Personal opinions by Frances state that "BIM is a technology that has made this integrated project delivery method feasible, just brought it to life. All of the major participant's teams were engaged in BIM model including structural, exterior wall, MEP, fire protection and the construction manager.

Visualization & Sustainability:

The design team at CO Architects says, "You could design a sustainable building without BIM. However, what you cannot do is design and construct it in a truly sustainable way that goes beyond the traditional approach, such as use of the LEED checklist or the Green Guide for Health care.

Collaboration

During the design phase, architects, engineers, and MEP contractors used the digital models to verify design concepts, share expertise and resolve issues. During construction phase, contractors used BIM to develop working drawings and prefabricate components.

Figure-11: PMCW BIM model.
Source: CO Architects project documentation.

Figure-12: Integrated BIMmodel of the hospital.
Source: CO Architects project documentation.

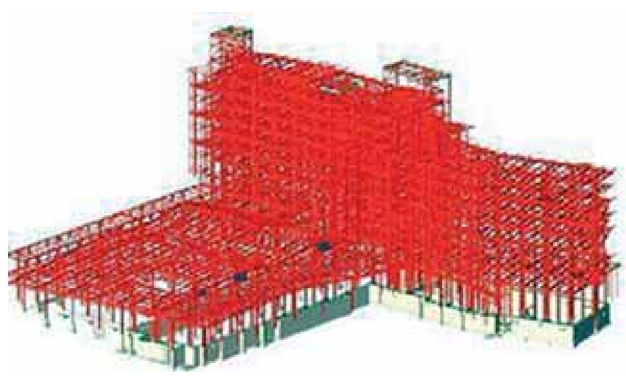


Figure-13: Structural model of the hospital.
Source: CO Architects project documentation.

Key BIM Uses

This project is first healthcare facility to use BIM tools like Autodesk Revit. The digital model went through multiple

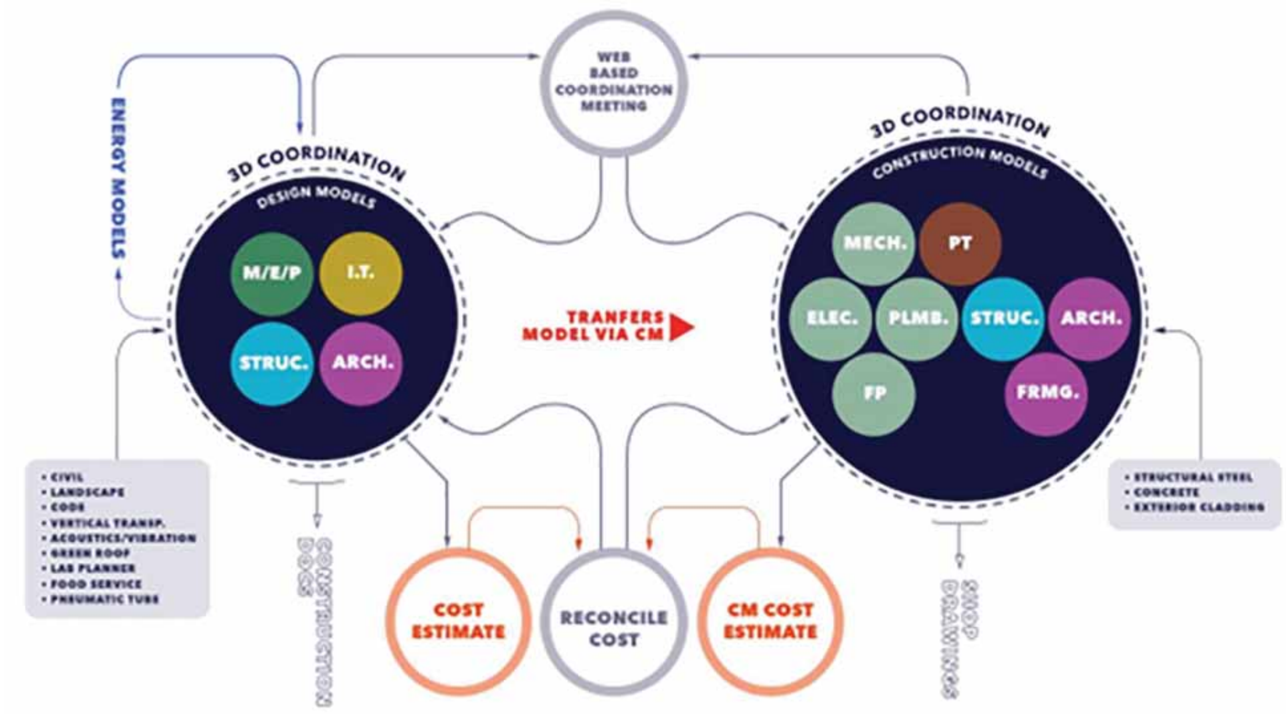


Figure-14: Project BIM work flow.
Source: CO Architects project documentation.

software updates, which in this case did not hinder design teams' capability and efficiency. The BIM features used by the project designers are:

- Centralization of the project via networking
- Collaborative project team work
- Automated quantity and cost management
- Automated production of the 2D drawing
- Parametric object-oriented change management
- Integration of facility management in BIM process
- Simulation of the construction process
- Automated pro forma linkage to BIM model

Structural and Mechanical Stage

<u>Structural System</u>

To optimize the structural system, the subcontractors evaluated the original "two ways' truss system. The design team made a decision to remove secondary trusses and used one way. This change due to BIM structural analysis and site simulation simplified the scope of the project with no major architectural design changes. Major benefits after the construction:

Figure-15: Aerial view of PMCW.
Source: CO Architects project documentation.

- The material and labour cost save 2 million.
- Schedule of steel contract was completed 4 weeks ahead.
- Because of the modified incentive contract, $ 6 million of steel contract was returned to the owner.
- No changes in the order were required for structural steel.

Figure-16: Rendered model of graduate school of management.
Source: Sasaki Associates.

Figure-17: Rendered model of graduate school of management.
Source: Sasaki associates official website.

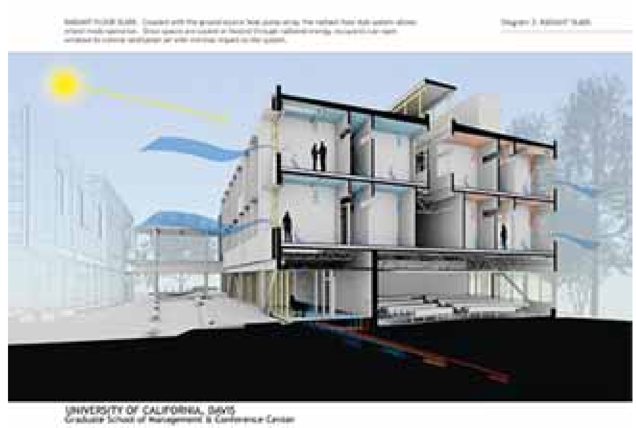


Figure-18: Sun study and solar angles.
Source: Sasaki associates official website.

MEP & Overhead Coordination

The green roof on the diagnostic and treatment wing was accomplished because of an integrated team with clear objectives; it provided the patient with a soothing view of nature. It was an essential part of green design goals. As it accumulated a huge span.

Key BIM Uses:

The surgical area underneath required a column free area for maximum usage of the space, this flexibility was essential for the future equipment requirements for the building.

- Complete space planning freedom (column less)
- Adaptability for future planning needs
- Overhead structure and access for the vast array of elements in need of support.
- Adaptability to re-engineer overhead.
- As built model documentations to facilitate future.

Construction Stage

For the accuracy that schedules require, a proper design built delivery must be applied. The BIM model, with relative performance specifications, presented a straightforward base for the work on components.

Contractor Use of BIM:

- Developed working drawings directly from model.
- Prefabricated components using accurate digital models.
- Simulated construction process to optimize sequencing.

Exterior Cladding System

- BIM-produced digital prototypes ensured accuracy and reduced rework.
- Supported parallel activities of different teams.

Workflow Features Used

- Automated Quantity & cost management
- Automated 2d Drawings from model
- Parametric change management

Graduate School of Management (GSM)

Introduction

This 83,000 Sq. Ft facility incorporates the UC Davis Conference Centre and Maurice J. Gallagher Jr. Hall. The building is situated at the southern end of the institute. It is a three-storey building consisting of a restaurant, office space, meeting rooms and a ballroom. Sasaki the design firm exceeded project goals while in collaboration with Sundt Construction.

Figure-19: BIM structural and MEP model combined of GSM.
Source: Sasaki associates official website.

Figure-20: Interior and exterior of GSM.
Source: Sasaki associates official website.

Conceptual Stage (Early Design & Planning for GSM)

<u>Purpose</u>

To create a sustainable and future-ready home for UC Davis Graduate School of Management.

<u>BIM Role</u>

• A preliminary Revit model was developed within days of receiving the RFP, tailored to GSM's academic and conference needs.
• Navisworks fly-through allowed GSM stakeholders to visualize classrooms, offices & meeting areas, approving layouts quickly.
• Real-time costing in Revit helped balance high-quality design (glass facades, open learning spaces) with GSM's budget requirements.

Structural & Mechanical Stage (Integration for GSM Facilities)

• Integrated Academic Facility Design: BIM enabled close collaboration of architects, structural and MEP engineers to align Gallagher Hall's lecture halls, offices, and collaborative spaces with efficient structural and mechanical systems.

• Geothermal Array & Radiant Slab:
o BIM analysis proved that geothermal integration could reduce HVAC loads by 100 tons, cutting costs and boosting efficiency.
o Radiant slab modeling demonstrated multiple benefits essential for GSM's long-term use, silent operation thermal comfort, and lighting support.

• ***Outcome for GSM***

Facility turned out 34% more energy efficient than baseline, elevating certification from planned LEED silver to LEED Gold, giving GSM a sustainable identity.

Construction Stage (Execution & Delivery for GSM)

• Construction Sequencing in Networks
o Gallagher hall was designed to accommodate universities future needs. Susan Rainier, project manager, explains: "We chose to leverage our ideas about the building to facilitate a competitive bidding process that would save time." The management office developed a broad approach of evaluation criteria, which included innovation, construction schedule, value and sustainability. This was also strengthened by making Gallagher Hall a LEED silver standard project (Sasaki, 2010).
o In night time, ground source array's cooled water circulates directly to charge the radiant slab and floor systems to provide efficient cooling. The water Consumption of the mechanical system is reduced substantially by heat pump array. The exposed slab system captures the following functions from single component expenditure:

1. Silent operation
2. Thermal mass
3. Support for lighting
4. Thermal comfort
5. Active HVAC system
6. Extended component life cycle

• Parallel Workflows
o Gallagher Hall was designed with significant pace, accuracy, and cost-effectiveness by the design/construction team using building information modelling (BIM). Strachan Forgan, director of digital design says, "BIM provided deep project insights from the very beginning, about how quickly and cost-effectively we could deliver a noteworthy project."
o Both the design and construction firms (Sundt and Sasaki) credit Autodesk's BIM solution for providing integrated design. The structural and the mechanical

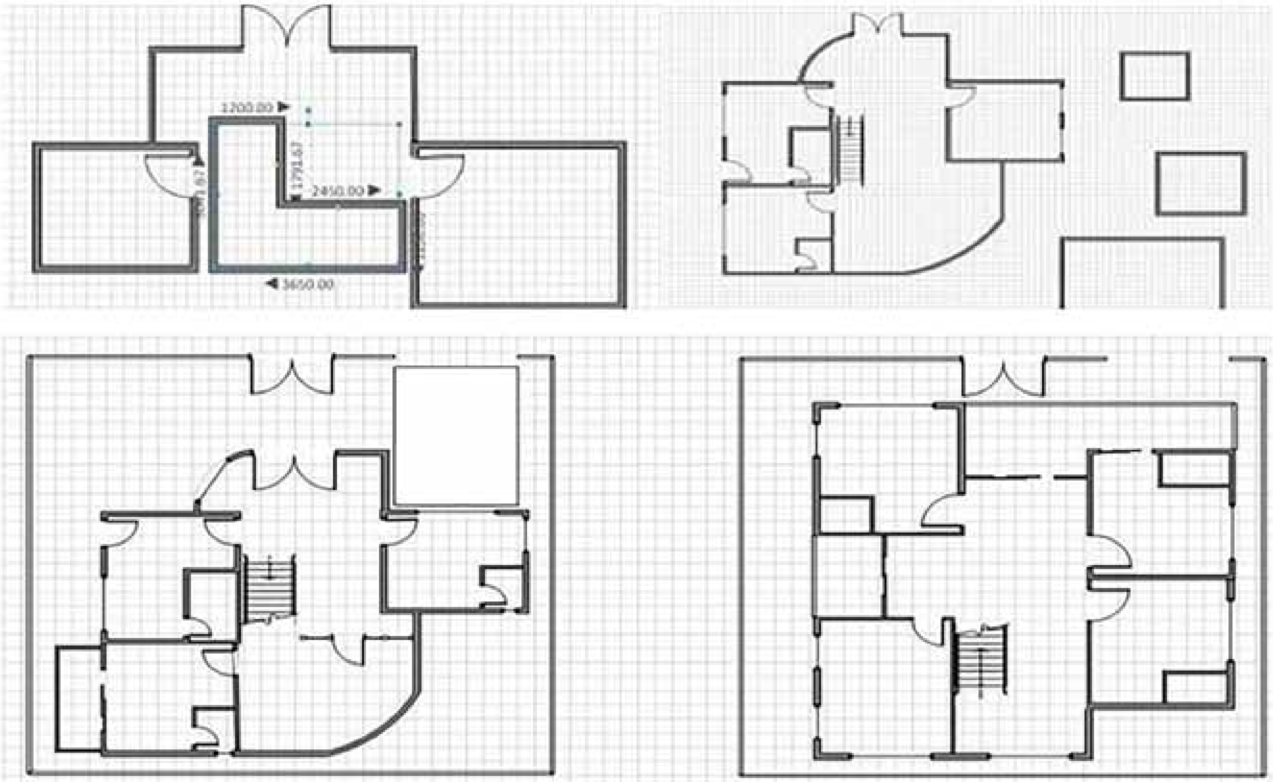


Figure-21: Initial floor plan and layouts of microsoft visio.

engineers were able to project the cost, sustainability and materials insights continuously through proposal stage.

- Budget & Timeline Control:

o Facility turned out 34% more energy efficient than baseline, elevating certification from planned LEED silver to LEED Gold, giving GSM a sustainable identity.

o The design firms emphasized in balancing the design aesthetic with the awareness of cost as it was likely to play a key factor in winning the project. Instead of compromise on appealing features, design/ built firm performed a real-time costing exercise by the material take off features in Revit. Project manager for Sundt Marie Christ stated, “The amount of glass and the façade material were modified by the architects, giving us the take offs.

o “When developing a design/built proposal there can be temptations to be conservative” adds Woody (Sundt project architect). “BIM gave the design team a precise view of how their design preferences influenced costs. For example, the team did not have to cut short the quantity of the windows just to be on the safe side. Instead, they optimized the use of appealing features.”

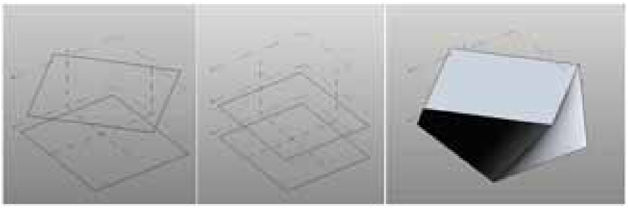


Figure-22: Parametric object created from Autodesk Revit.

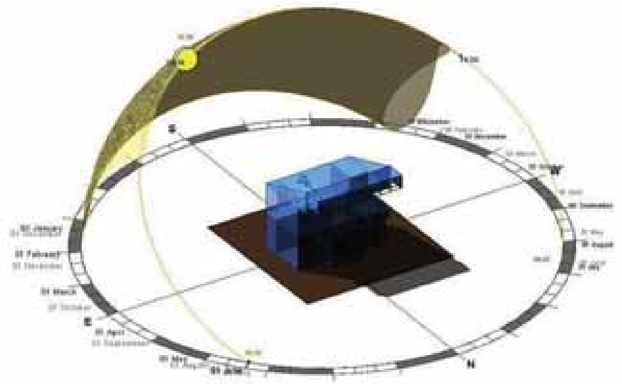


Figure-23: Best orientations for the building.

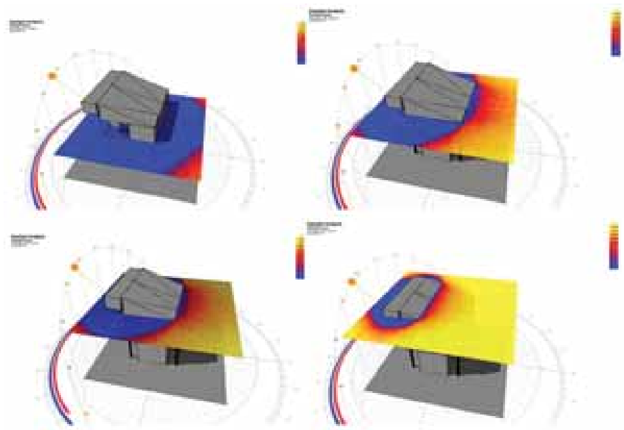


Figure-24: Daylight analysis in layers.
Source: Created for Autodesk Revit.

• Final Delivery:

o Gallagher hall, home of GSM, was completed one month ahead of schedule (Sept 2009), setting an example of efficient project management that aligns with GSM's mission of innovation and leadership.

o The busy schedule made the team to continue with project detailing and planning the construction process simultaneously. The structural engineers of Rutherford and Chekene developed the preliminary structure model. Their senior project engineer Tanjeet Juneja, mentioned, "We had a reasonably detailed model of the structure from the beginning, and all our work was coordinated, correcting glitches as we went.

o "Evaluating the entire building model with our subcontractors permitted us to communicate precisely what we needed them to accomplish," says Woody. "Creating Sequence for the features within Navisworks allowed us the ability to split the tasks, making it simple for crews to carry out proficiently. With BIM we visualized each task essential to complete Gallagher Hall so when it came to building it, it was like everything had been done before."

EXPERIMENTAL PROJECT

Conceptual Stage

At the conceptual stage, the project focused on initial layouts, planning, and performance modelling.

• Layouts & Digital Tools

Microsoft visio was used for preliminary design layouts due to its intelligent building elements (walls, doors, windows) that automatically adjust when placed or joined. Autodesk Revit was applied to create parametric design objects, enabling multiple design iterations while saving time in the end.

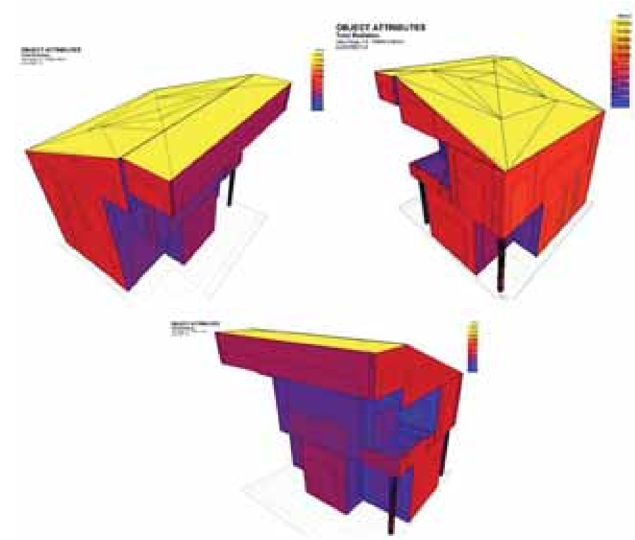


Figure-25: Solar radiation analysis.
Source: Created for Autodesk Revit.

• Weather Data Analysis

Autodesk Green Building Studio was integrated with Revit models to analyse site-specific weather data. This allowed evaluation of thermal gains, optimal building orientation, and weekly temperature variations. Solar studies further guided the placement of openings, projections and shading devices to improve daylight use and energy efficiency.

• Performance Modelling

Early performance modelling helped in determining daylight distribution, shadow patterns and ventilation strategies. Wind flow simulations, represented in point clouds, and allowed the project to minimize HVAC dependency through improved natural ventilation.

Structure and Mechanical Stage

Once conceptual decisions were finalized, the project moved to the integration of structural and MEP systems.

• Structural Model: The finalized architectural model was linked with Revit Structure to generate the structural framework. Overlapping models minimized errors, reduced rework, and supported cost efficiency.

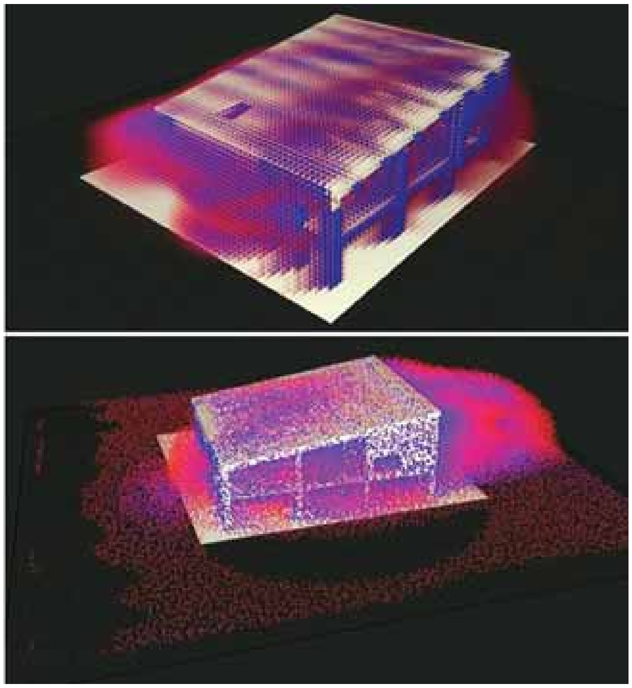


Figure-26: Annual wind analysis.
Source: Created for Autodesk Revit.

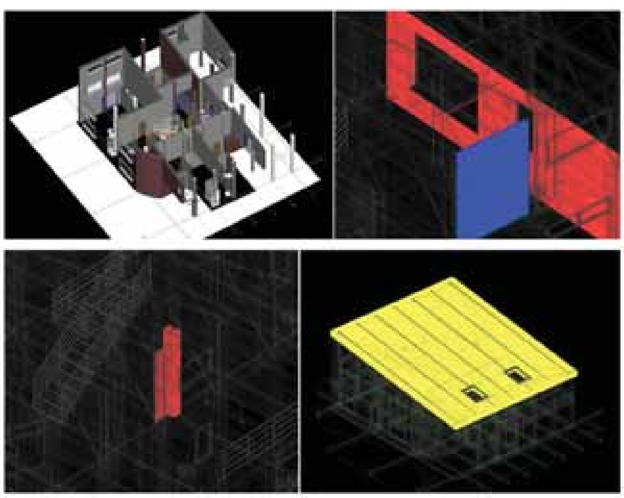


Figure-29: Autodesk revit conceptual energy analysis report.

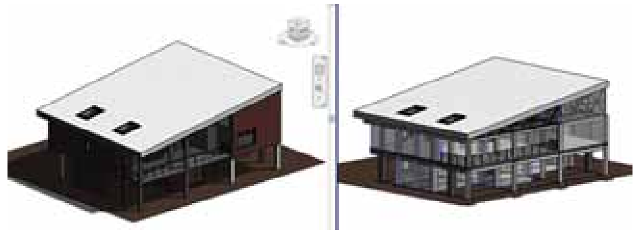


Figure-27: Autodesk revit architecture and structure models.

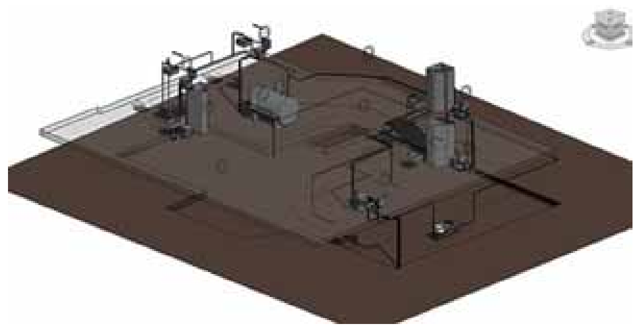


Figure-28: Mechanical, Electrical and Plumbing Model.

Location:	Rushoim, Manchester M13, UK
Weather Station:	140750
Outdoor Temperature:	Max: 88ºF/Min: 24ºF
Floor Area:	2208 sf
Exterior Wall Area:	4578 sf
Average Lighting Power:	1.01 w/ft^2
People:	7 People
Exterior Window Ratio:	0.62
Electrical Cost:	$0.15/ kwh
Fuel Cost:	$1.12/ Therm

Figure-30: Autodesk revit conceptual energy analysis report.

• Mechanical, Electrical & Plumbing (MEP): The integrated model was further connected to Revit MEP, which provided parametric libraries for mechanical, electrical, and plumbing elements. The AutoRoute generator ensured optimal pipe and duct routing, supporting efficiency and reducing conflicts.

• Digital Twin Development: By integrating architectural, structural, and MEP models, the project created a digital twin, a complete virtual representation of the intended building.

Construction Stage

Before moving toward execution, digital coordination and clash detection were carried out to ensure construction efficiency.

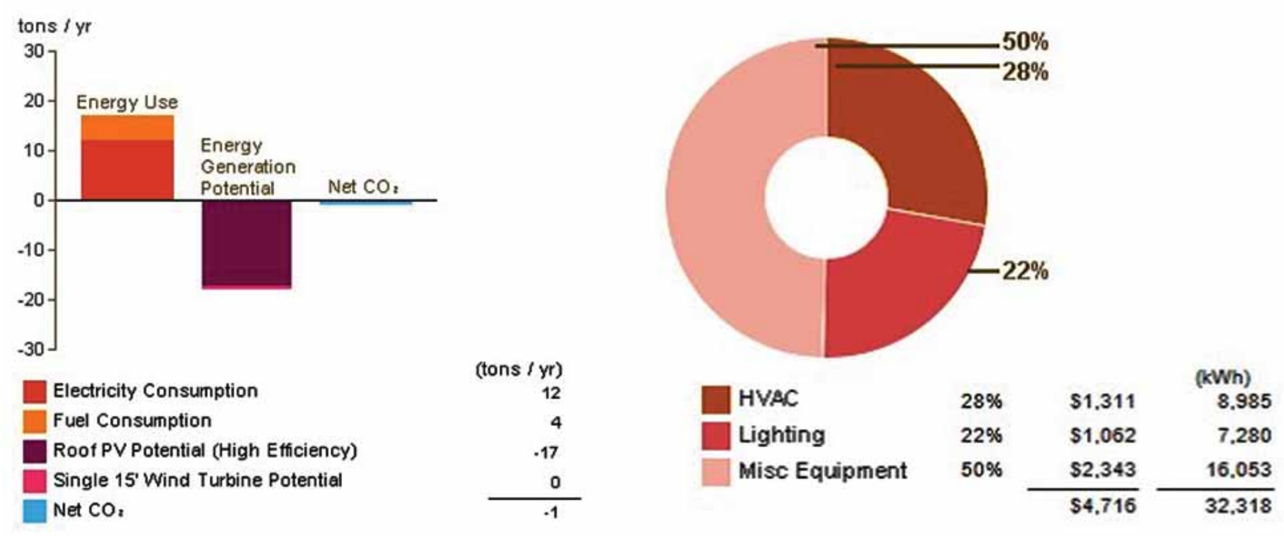


Figure-31: Autodesk revit conceptual energy analysis report.

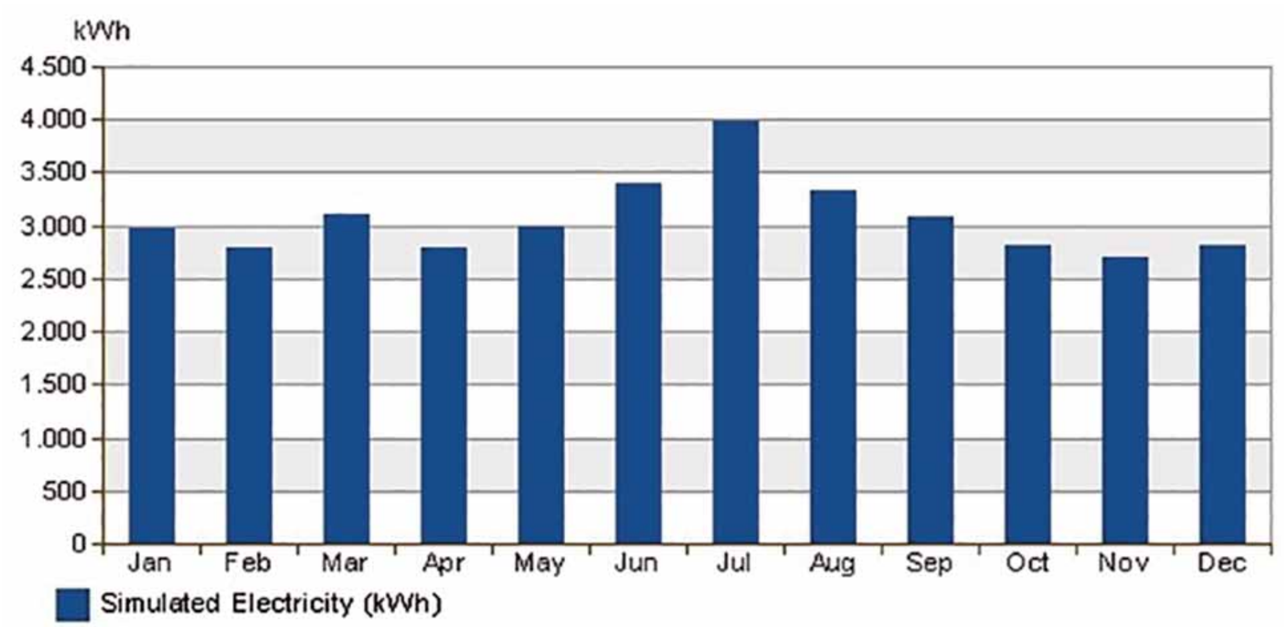


Figure-32: Autodesk revit conceptual energy analysis report.

• Clash Detection:
Autodesk Navisworks was used to detect collisions among architectural, structural, and MEP components. Specialists from different disciplines reviewed these clashes to resolve potential conflicts before construction.

• Performance Reports:
Online tools such as Revit Conceptual Energy Analysis and Green Building Studio generated detailed reports covering energy use, carbon emissions, heating/cooling loads, and ventilation.

• Sustainable Guidelines: These reports informed construction decisions, ensuring materials and methods aligned with sustainability goals and economic efficiency.

Integration of Models:

As the Architectural model is created and all the layouts are finalized, this model is linked with Revit structure program and structural model is created. By overlapping the models, many errors can be reduced and design can achieve greater integration, which decreases the time spent in reworks and makes the project cost effective.

Autodesk Online Analysis Report Guide

With the new online services, Autodesk Revit Conceptual Energy Analysis Report/ Green Building Studio a detailed performance report of the building can be generated as it highlights the energy consumption according to the material and other factors such as carbon emission heating and cooling loads and ventilation.

DISCUSSION

This study has highlighted the significant role of BIM in promoting sustainable building design by enabling an integrated, data-driven, and collaborative workflow. Through performance-based analyses in the early design stages, BIM allows architects to make informed decisions that directly influence building efficiency, particularly in relation to daylight, wind, temperature, and energy performance. The integration of structural and MEP models with the architectural model further strengthens collaboration and reduces discrepancies across disciplines, ensuring more coordinated design outputs. A major advantage of BIM lies in its ability to quantify sustainability measures, such as carbon emissions, energy loads, and material performance. This transforms sustainability from a qualitative aspiration into a measurable design objective. Moreover, tools like clash detection significantly reduce potential construction conflicts, leading to faster project delivery and cost savings, while the digital prototype extends value into facility management. Despite these benefits, challenges persist. File compatibility and interoperability issues continue to disrupt the seamless integration of various software tools, even with IFC support. Similarly, when parametric objects are transferred across platforms, the loss of embedded geometric rules hinders effective coordination. Traditional learning approaches and complex software interfaces further slow adoption. Finally, the scope of current BIM applications often prioritizes design integration but gives limited attention to construction and fabrication processes, where greater focus could further enhance project sustainability.

CONCLUSION

This research has demonstrated that BIM can be a powerful enabler of sustainable building design by supporting early-stage performance analysis, enhancing collaboration across disciplines, and improving construction efficiency through clash detection and digital prototyping. The findings underscore BIM's capability to integrate environmental and economic sustainability goals into the architectural, structural, and MEP design processes. However, the study also revealed several limitations. Interoperability between different software versions remains a key barrier, as do challenges related to parametric object transfer and third party plug-in compatibility. The reliance on Autodesk products in this research restricted broader exploration of alternative tools, while the steep learning curve continues to discourage widespread adoption, particularly among practitioners with limited digital expertise. Future research should focus on improving interoperability standards, expanding the role of BIM into fabrication and construction workflows, and simplifying software interfaces to lower the learning threshold for designers. With these advancements, BIM has the potential to move beyond design integration and become a holistic framework for achieving sustainability throughout the entire building lifecycle.

REFERENCES

AIA TAP/BIM Awards report, 2010, Using BIM and IPD to design and build the hospital of the future.

Autodesk, (2009),"Using Autodesk Ecotect Analysis and Building Information modelling", Autodesk Ecotect Analysis user guide.

Bootee. D.N and Belie. P, 2005, Scholars before researchers: centrality of literature review in research preparation page 202, educational researchers.

Biggram. J, 2008, succeeding with your Master's Dissertation, A step by step handbook, McGill Open Press.

Bernstein H.M, Jones S.A & Russo M.A, 2010, Smart Market Report, McGraw-Hill Construction.

Collins. H, 1984, Researching Spoon bending, In Bell, C and Roberts, H, Social Researching, London, Routledge and Kegan Paul Ltd Page 266.

Den Helm. P, 2009, IFC-based clash detection for the open-source BIM server, TNO NL.

Eastman .C, Teicholz. P Sacks. R, Liston. K, 2011, BIM, Handbook, A guide to contractors, John Wiley & Sons.

F. Levy, 2012, BIM in Small Scale Sustainable Design, John Wiley & Sons, Inc., Hoboken, New Jersey.

Gray. D, 2009, Doing Research in Real World, SAGE Publications LTD.

Golzarpoor, H. JULY 2010. Thesis on APPLICATION OF BIM IN SUSTAINABILITY ANALYSIS. Master of Science (Construction Management), University Technology Malaysia.

Klitgaard & Kierkegaard & R.L Jensen, 2007, Evaluation of BIM for conceptual architectural design analysis, University of Aalborg, Department of Civil Engineering, DK.

Krygiel, E. & Nies, B. 2008. Green BIM: successful sustainable design with building information modelling, Indianapolis, Ind., Wiley Technology Pub.

Lee, G. 2006. Specifying parametric building object behaviour (BOB) for a building information modelling system.

McCollum. B, 2006, Autodesk Revit Systems: BIM for MEP Engineering, Autodesk, Inc.

Smart Market, 2010, Green BIM How building Information Modelling is contributing to Green Design and construction, McGraw Hill Constructions.

Stake, R.E, 2000, The case study method in social inquiry, R. Goom, M. Hamersley and P. Foster, Case Study Method: Key Text. London, SAGE.

Sasaki Associates and Autodesk Journals, 2010, Sustainable. Cost effective. Ahead of schedule, Autodesk LTD.

Rubben. A, Greg B., (2009), the intersection of BIM and sustainable design, Structure Magazine Page 16 – 17.

Thuesen. N (2009), "BIM and the integrated design process". Department of Architecture and Design, Aalborg.

Thuesen. N, 2009, "Evaluation of BIM and Ecotect for the conceptual architectural design analysis", University of Aalborg, Department of Architecture and Design, DK.

Well and. R.A, Briggs. G, 2009, Autodesk. "The intersection of BIM and Sustainable Design", Structure Magazine Page 222.

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING
Volume 35 Issue 2
ISSN (P) 1728-7715 - ISSN (E) 2519-5050
Journal DOI: www.doi.org/10.53700/jrap_neduet
Issue DOI: www.doi.org/10.53700/jrap3522025

A GIS BASED MULTI CRITERIA DECISION ANALYSIS FOR EV's (ELECTRIC VEHICLES) SOLAR POWERED CHARGING STATIONS SITE SELECTION IN ISLAMABAD, PAKISTAN

Huzaifa Sarfraz*, Saleha Ansari**, Syed Abdul Rehman Peerzada, Sana Asif****, Abdul Waheed********

Article DOI:
www.doi.org/10.53700/jrap3522025_3

Article Citation:
Sarfraz H., et. al., 2025, A GIS Based Multi Criteria Decision Analysis for EVs (Electric Vehicles) Solar Powered Charging Stations Site Selection in Islambad, Pakistan, *Journal of Research in Architecture and Planning,* 35(2). 36-54.

* Chief Product Officer, School of Civil and Environmental Engineering National University of Science and Technology, Islambad, Pakistan.
huzaifasarfraz291@gmail.com
** Project Manager Specialist, MSc Urban and Regional Planning, School of Civil and Environmental Engineering National University of Science and Technology, Islambad, Pakistan.
salehaansari18@gmail.com
ORCID: 0009-0002-6544-4334
*** Teaching Assistant, MSc. Geoinformatics, Aalto University, Espoo, Finland
syed.peerzada@aalto.fi
**** Urban Planner, School of Civil and Environmental Engineering National University of Science and Technology, Islambad, Pakistan.
sana.abajwa19@gmail.com
***** Ph D., Assistant Professor Department of Urban and Regional Planning, School of Civil and Environmental Engineering National University of Science and Technology, Islambad, Pakistan.
drwaheed@nit.nust.edu.pk
ORCID: 0000-0002-0162-9471

ABSTRACT

Electric vehicles (EVs) are gaining popularity as a more sustainable substitute for traditional gasoline-powered automobiles. They not only produce fewer pollutants but also contribute to mitigating climate change and improving air quality. However, maintaining these cars calls for suitable charging infrastructure, which may be really difficult for developing nations like Pakistan. This study aims to identify ideal locations for solar energy-based charging stations in Islamabad, Pakistan, using a multi-criteria decision analysis (MCDA) method based on geographic information systems (GIS). The study uses real-world constraints with structured weighing methodology which is underexplored in the South-Asian context. This strategy include several variables, including solar availability, land use patterns, accessibility, and preexisting infrastructure. A weighted linear overlay was used to create the final suitability map after methodologies like the Analytic Hierarchy Process (AHP) were used to set the weights for these parameters. The best locations for charging stations were found using this map. The second part of this study aims to develop a mobile application to reduce range anxiety, and create a user-friendly platform that supports the growth of electric vehicle adoption in Islamabad.

Keywords: GIS, solar power, climate change, electric vehicles, charging stations, AHP.

INTRODUCTION

The automobile sector has become one of the most significant industries in the world, not just economically, but also in terms of research and development. Electric vehicles (EVs) are rapidly becoming a popular mode of transportation worldwide, as they offer several benefits over traditional gas-powered vehicles. Pakistan, facing numerous cross-sectoral and multifaceted challenges, has recently initiated a transition from internal combustion engine (ICE) vehicles to electric vehicles (EVs). To facilitate this shift, the country has introduced a range of policy measures targeting automakers, consumers, and international stakeholders. By embracing electric mobility, Pakistan can reduce its dependence on petroleum-based energy sources and promote the use of domestically generated electricity. However, the growth of electric vehicle (EV) infrastructure in Islamabad, and by extension the country, is hampered by numerous real-world limitations that prevent their mass-scale uptake. Even as one of the few cities with more stable power and planning infrastructures, Islamabad does not have a well-spread network of EV chargers, with the majority confined to private or commercial installations. The unreliable power supply and small capacity of the current grid (Wahid, 2021) also limit the feasibility of extensive charging infrastructure, as extensive deployment could impose further strain on power distribution grids. High upfront costs of EVs, batteries, and charging equipment, coupled with limited affordability and limit adoption to high-income segments, lowering market incentives for expansion of infrastructure. Implementation of policy also is not strong; while the National Electric Vehicle Policy (NEVP) sets out a basis, regulatory uncertainty over land allotment, private investment, and electricity tariffs has hampered pragmatic advancement. Further, urban planning and land-use regulations in Islamabad complicate the provision of space for public charging stations, particularly in residential and mixed-use areas. Lack of domestic manufacturing capability, technological skills, and trustworthy spatial information further constrains operational viability and planning effectiveness. Moreover, public knowledge and trust in EV technology are low, with apprehensions regarding range, maintenance, and long-term durability. Islamabad's solar resource offers a sustainable renewable source for charging infrastructure, yet integrating solar systems on a large scale demands significant capital outlays and coordination requirements. Together, these limitations underscore the intricate interrelationship between policy, economics, infrastructure, and social preparedness that continues to influence the EV transformation of Pakistan's capital city. One of the primary concerns is the issue of range anxiety (Taub, 2017) which is the limited driving distance of electric vehicles on a single charge. This study aims to discuss this problem. However, addressing this issue requires the establishment of a robust charging network that ensures convenient and accessible charging stations (Khurrana, Kumar and Sidhpuria, 2020) across the country. Without a well-developed charging infrastructure, the widespread adoption of EVs remains a challenge, making the development of charging stations a key priority for a successful transition to electric mobility.

Research Objectives

Following are the research objectives of this study.

- To identify the most suitable locations for electric vehicle solar powered charging stations in Islamabad

- To develop a mobile application to enhance the efficiency, sustainability, and user experience of EV (electric vehicle) infrastructure in the city.

We already know that the adoption of electric vehicles (EVs) in urban areas, including Islamabad, has been hindered by the lack of adequate and accessible charging infrastructure (Mahboob et. al., 2021), coupled with the growing concerns of range anxiety among EV (electric vehicle) owners. The absence of strategically located charging stations and the limited availability of charging slots during peak hours further exacerbates this issue. This creates significant barriers to the widespread adoption of electric vehicles, undermining efforts to transition to more sustainable transportation systems. Additionally, the challenges of battery management, including the limited lifespan (Martins, et. al., 2021) and charging constraints of EV (electric vehicle) batteries, call for innovative solutions such as an (internet of things) IoT-based battery-swapping system. A lack of integration between charging infrastructure and renewable energy sources further contributes to the inefficiency of existing systems, (Abro, et. al., 2023) making them less sustainable in the long run. To address these challenges, this study focuses on two main research objectives: first, to identify the most suitable locations for EV (electric vehicle) charging stations in Islamabad through GIS-based multi-criteria decision analysis (MCDA), and second, to design a mobile application that will enhance the experience of electric mobility in the city and support electric vehicle infrastructure. By achieving these objectives, this study aims to mitigate range anxiety, optimize the placement of charging infrastructure, and create a user-friendly platform that supports the growth of electric vehicle adoption in Islamabad.

LITERATURE REVIEW

Over the past few years, the global and Pakistani demand for electric vehicles (EVs) has followed a consistent rising trend with increasing fuel prices, environmental consciousness, and the government-sponsored promotion of cleaner motoring. Although the overall Pak automotive market continues to be led by internal combustion engine (ICE) vehicles, their growth has begun to slow due to mounting operational and maintenance expenses. Compared to this, EV uptake although, still in its infancy has been picking up, especially in large urban areas like Islamabad, Karachi, and Lahore, where pilot charging points and import subsidies have started to create consumer interest. Industry estimates and trade figures suggest that EV imports and registrations have picked up substantially after the launch of the National Electric Vehicle Policy (NEVP) in 2019, indicating a budding change (Asim, et. al., 2022) in mobility attitude. This relative growth in EVs compared to ICE vehicles emphasizes the imperative for creating a well-planned charging system capable of sustaining this shift, alleviating spatial disparities, and assisting in a sustainable and inclusive urban mobility system.

EV (Electric Vehicle) Charging Infrastructure in Pakistan

A major obstacle to electric vehicle (EV) adoption in Pakistan is the lack of infrastructure, particularly charging stations(Ashraf, et. al., 2021), which are mainly concentrated in urban areas like Karachi, Lahore, and Islamabad. This geographic disparity leads to range anxiety and deters potential buyers, especially in suburban areas or other cities which do not have supporting electric vehicle infrastructure. Economic barriers also play a significant role, (Nadeem, et. al., 2022)with high upfront costs and import taxes for electric vehicles ranging from Pakistani rupee Rs. 1.5-2 Crore (approximately 70,000 USD) for models like the Deepal L07 and BYD Seal—making them unaffordable for most consumers. Furthermore, Pakistan's energy crisis raises concerns about the ability of the grid to handle increased charging demand, (Mouhy-Ud-Din, et. al., 2024) especially given frequent load shedding and reliance on fossil fuels. Consumer skepticism about electric vehicles performance, including battery life and maintenance, is compounded by limited technical expertise and servicing options, further hindering adoption. Though Pakistan's electric vehicle (EV) sector is rapidly growing with strong support from the Special Investment Facilitation Council (SIFC), which aims to establish 10,000 charging stations by 2030 there is still a lack of information regarding where these stations will be planted. Key milestones included in the report by Special Investment Facilitation Council (SIFC) are a 44% reduction in electricity rates for charging stations, $90 million allocated for infrastructure, (Duan, et. al., 2022) and a $250 million commitment from Chinese manufacturer ADM Group to build an EV manufacturing facility. The initiative is expected to save on fuel imports, reduce carbon emissions, and promote sustainable transportation.

This study aims to identify the optimal locations for EV charging stations (EVCSs) with maximum solar energy potential. Expanding the use of renewable energy sources serves two key objectives; reducing greenhouse gas emissions and as well as enhancing energy security (Kanwal, et. al., 2022) by decreasing reliance on fossil fuels. Given the strain on local electrical grids, more abundant and cost-effective renewable sources of energy like solar and wind are essential. Research studies highlight that achieving CO_2 reduction targets requires significant integration of photovoltaic systems and electric vehicles, (Parikh, Shah and Prajapati, 2023)underscoring the need for daytime charging infrastructure, particularly near workplaces, to maximize renewable energy utilization.

IoT (Internet of Things) in EV Infrastructure

Pakistan's transportation industry has a growing share in electric vehicles but still lacks the infrastructure to support this growth. Internet of things or IoT in electric vehicle infrastructure is a way of enhancing electric vehicular infrastructure by enabling real-time communication, allowing automation and data-driven decision making for users. IoT-powered smart charging stations can monitor power usage, (Bathla, et. al., 2022)the availability of power and even performance while allowing the user to locate, reserve and pay for the charging via mobile app. Currently Pakistan lacks IoT in (Electric vehicle) EV infrastructure. By incorporating this technology, remote monitoring and predictive maintenance will help detect faults early and reduce downtime (Rajagopalan, et. al., 2024) and maintenance costs as well. IoT will also facilitate vehicle-to-grid (V2G) integration, enabling the cars to return excess energy to the grid for improved energy stability. Moreover, IoT in electric vehicular infrastructure improves the user experience through mobile applications that provide real-time battery status, charging locations and automated billing.

Battery swapping is also an imperative part of electric vehicle infrastructure. Battery swapping has gained popularity due to its multiple benefits, (Sankaran and Venkatesan, 2022) including reduced charging time, improved battery lifespan, and better load management on the power grid. Studies suggest that integrating battery swapping systems with charging stations and residential buildings can minimize operational costs through cooperative management. One of the key advantages is fast charging, as replacing a depleted battery with a fully charged one significantly reduces downtime, (Sierra and Reiders, 2021) enhancing EV productivity. Traditional charging methods can extend travel time, whereas battery swapping allows users to resume their journey quickly. Additionally, reducing strain on a single battery extends its lifespan, lowering long-term ownership costs and making EVs a more viable option. Overall, battery swapping presents an efficient and time-saving solution, addressing key barriers to EV adoption by improving infrastructure and enhancing user convenience.

GIS (Geographic Information System) Based Site Selection

Multi-criteria decision analysis- MCDA is a collection of systems analysis techniques for handling complex decision-making issues like site selection. Multiple studies used MCDA for the selection of suitable sites for charging stations such as; Analytical Hierarchy Process (AHP), Weighted Linear Combination (WLC), Analytical Network Process (ANP), Fuzzy AHP (Fuzzy analytical hierarchy process), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), and a combination of these. (Adem and Geneletti, 2018)

One such study for Ankara, (Erbaş, et. al., 2018) used a combination of the Fuzzy analytical hierarchy process (FAHP) and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) for the optimal siting of electric vehicle charging stations. The study considered 15 factors depending on environment, economics, and urbanity. GIS (Geographic Information System) and MCDA were employed for finding suitable locations for charging stations. Furthermore, TOPSIS was applied to rank alternative locations. Similarly, another study (Wang, et. al., 2024) combined Geographic Information System (GIS) and MCDA (multi criteria decision analysis) to select sites for installing PVCS (Photovoltaic Charging Stations) in Beijing, China.

This study employs AHP (Analytical Hierarchy Process) for site selection. AHP is a decision-making method that combines mathematics and psychology to structure and analyze complex problems. It uses expert opinions to assign scores, breaking down intricate issues into smaller, manageable components and (Tavana, et. al., 2023) organizing them within a hierarchical framework.

The AHP process involves three key steps:

- Clearly defining the problem to be addressed.
- Listing all possible solutions or alternatives.
- Establishing clear criteria and standards against which the alternatives will be evaluated.

The importance of each criterion is determined through pairwise comparisons, where two factors are evaluated at a time. Finally, based on the numerical values derived from these comparisons, the most optimal solution is selected.

Mobile Applications for EV (Electric Vehicle) Infrastructure

There is a growing trend in using mobile applications for almost everything today. Currently there are no mobile applications in Pakistan that provide data related to electric vehicle (Shakeel, 2022) charging stations. For this purpose, this study will build a mobile application to facilitate user to easily find the location of these solar powered charging stations. Not only will the application help the EV (electric vehicle) driver to locate nearby charging stations, (Ibrahim, et. al., 2022)but it will also help the user to book a charging slot in advance. Another interesting feature that will be incorporated in the app will be to compare the cost of fuel and electric charging of the vehicle. React native expo will be employed for developing this app. For the database of application firebase will used. One such study (Ahmed, et. al., 2020) presented a system designed to monitor key parameters of EV charging stations. To improve the user experience, a mobile application was developed that enables users to view important metrics and receive notifications. The application offered a comprehensive overview of each charging station's performance, allowing users to make informed decisions by comparing stations, based on historical data and user feedback. By providing insights into the operational status and efficiency of the stations, this system helps users identify the best charging locations.

METHODOLOGY

The research is designed in two parts. A mixed approach is used in this study combining quantitative data analysis through geographic information system (GIS) and Analytical hierarchy processing (AHP) and then a qualitative design; mobile application and IoT (internet of things) system development. In the first part of this study, a multi-criteria decision method is used to find the optimal location for electric vehicle charging stations. Locating suitable sites for these stations involves numerous parameters and criteria. This process can be a time-consuming and complex process. However, efficient technology and geographic information systems- GIS techniques can facilitate this process. This study uses GIS to locate suitable sites for the installation of solar energy-based charging stations for EVs (electric vehicles) in Islamabad. For the selection of a suitable criterion, multiple aspects were considered with respect to their impact on the environment and geographical factors. The GIS layers were obtained using google maps and digital elevation model (DEM) data for Islamabad, Pakistan whereas, solar radiation is calculated using the spatial analyst tool and ArcGIS and reflect the most recent datasets available at the time of analysis. The methodology used in this study is adaptable to other urban areas with similar characteristics, provided that local datasets are available.

Study Area

The study area chosen for this study was Islamabad primarily due to the large number of electric vehicles (Ullah, et. al., 2023)already present in this city. Another rationale for selecting Islamabad is due to data availability, policy support for EV infrastructure, and feasibility for GIS-based analysis. Rural regions were not selected because of limited data availability. Islamabad, the capital of Pakistan, is located in the northern region of the country at the foothills of the Margalla hills. It is part of the Islamabad-Rawalpindi metropolitan area which is positioned at 33.69°N latitude and 73.05°E longitude, with an elevation of 540 meters above sea level and a total area

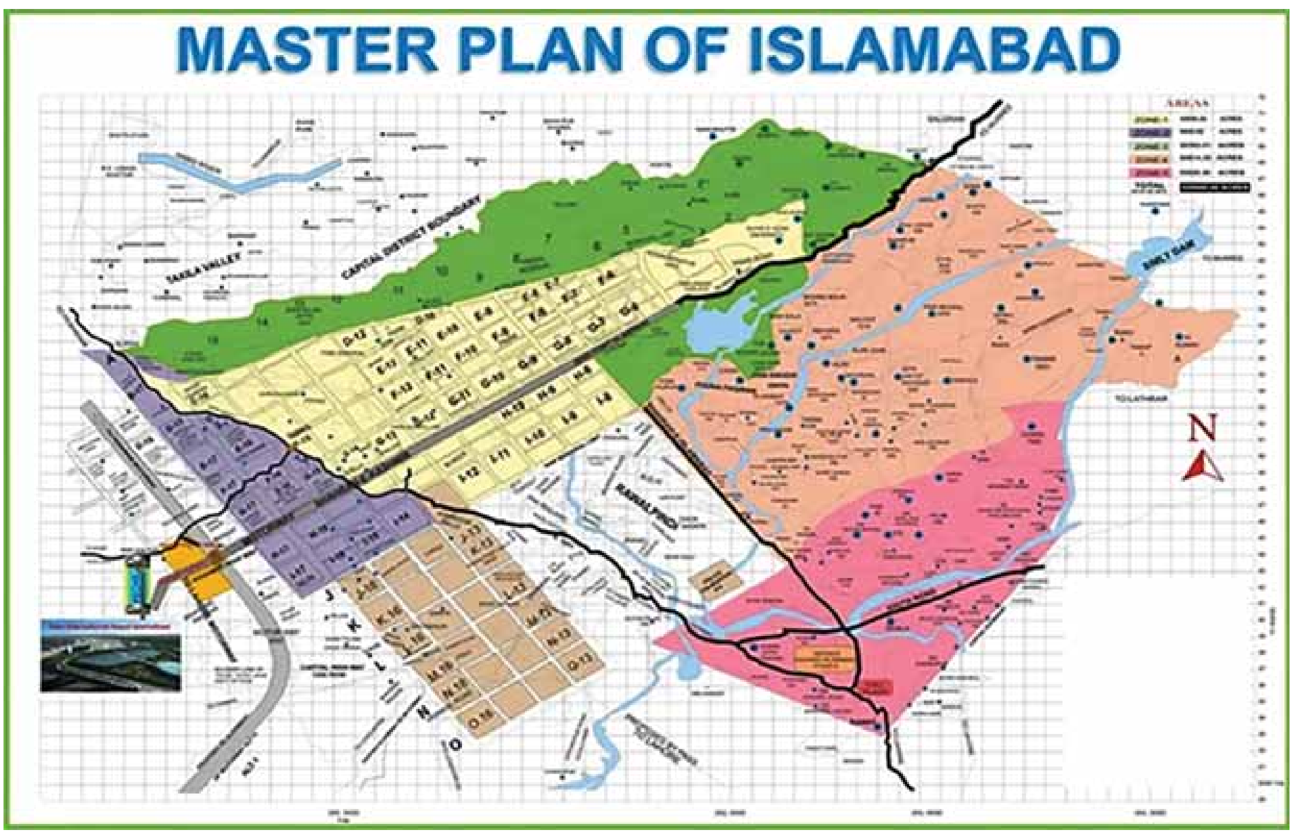


Figure-1: Study area map of Islamabad.

of 906 square kilometers in total. According to the Pakistan Bureau of Statistics, (Government of Pakistan, 2020) Islamabad has a population of 1.2 million as of 2020, with a rapid annual growth rate of 4.91%. the city is expected to grow to 2 million by 2030. The city hosts a diverse population, including residents from across Pakistan and some other countries. It is divided into five zones which are governed by the Islamabad Capital Territory (ICT) administration. As the political hub of Pakistan, Islamabad is home to key government institutions such as the Pakistan Supreme Court, Prime Minister's Secretariat, and the National Assembly. The Capital Development Authority (CDA) oversees urban planning, development infrastructure, the road networks, water supply and sewage systems of the city. In collaboration with the ICT administration and other regulatory bodies, the CDA ensures the city's planned and structured development, making Islamabad a rapidly growing and well-regulated metropolis. The map(figure-1) shows the different areas and planning of Islamabad. This map was generated using GIS (geographic information system) tool 'ArcGIS'.

Criteria for Site Selection

For the selection of a suitable criterion, multiple aspects were considered with respect to its impact on the environment and geographical factors. Literature review showed us that aspects such as solar potential, existing infrastructure, accessibility and low risk areas in terms of natural disaster and (Kaluza and Sierpinski, 2019) damage remain central in many studies while choosing the most suitable location for these charging stations. These spatial constraints were factored into the GIS-based MCDA model through specific exclusion and suitability layers. To select the optimal location for the solar powered charging stations several factors (see table-1) were considered in this study. These factors were then assigned weights using the Analytical Hierarchy Process (AHP). For Islamabad, each of these factors are explored further in the results section. These factors include;

Mobile Application Development

The second objective of this study was to develop a mobile application for users to facilitate them in locating these charging stations. For this purpose, a mobile application is developed which is Android and IOS-compatible application. Following are the core features of the application;

- The application displays a map that locates all the nearby charging stations for the user.
- The application enables the user to book a charging slot in advance to save the user time.
- The application provides a brief comparison between the fuel and electricity consumption of the vehicle depending upon the mileage of the vehicle.
- This application is also used for the battery swapping system. It shows the availability of batteries and their charging.

Development Environment

The project uses an open-source development approach, ensuring that all technologies—servers, databases, internal and external applications, the application engines, and even operating environments are governed by an Open-Source Community License. For application development, the study utilized React Native Expo, which serves as both a library and a framework for building native mobile applications on both iOS and Android. In addition, Expo is a suite of React Native-based tools and services that simplifies app development, (Kadrija, et. al., 2022) their testing, and their deployment. Another reason for using it is that it provides essential features such as a development server, simulator, and a library of pre-built components, thus making the development process more efficient and relatively easier. One of Expo's standout features is Over-the-Air (OTA) updates, (Danielsson, 2016) allowing developers to push updates directly to users without requiring approval from the App Store or Google Play. A major advantage of Expo is its ability to eliminate the complexities of setting up a React Native project. Developers can begin building apps immediately without configuring Xcode or Android Studio, streamlining the development workflow. To conclude, Expo and React Native were used because they are powerful tools for creating cross-platform mobile applications. They enable developers to build high-quality native applications for

Table 1: Factors considered for site selection.

Solar potential
Low flood risk
Existing fuel stations and parking lots
Existing land use and land cover
Primary roads
Slope of terrain
Aspect ratio
Elevation of site from sea level

both iOS and Android while minimizing platform-specific code by leveraging the flexibility of Java Script.

RESULTS

Solar Potential

This study focused on identifying optimal sites for electric vehicle charging stations, with a key aspect being the solar potential of Islamabad. The objective was to pinpoint locations with the highest solar exposure. To achieve this, we utilized ArcGIS for solar potential analysis, employing the Digital Elevation Model (DEM) of Islamabad (Haider, Sajid and Iqbal, 2021) as the primary dataset. The process involved preprocessing steps like projecting the data, ensuring linear units were in meters, and generating a hill-shade to enhance visibility of landscape features like trees and buildings. Solar radiation was then calculated using ArcGIS's Spatial Analyst tool, specifically the Area Solar Radiation tool. This tool factors in sun positioning and light-blocking obstacles, (Abro, et. al., 2022) producing a raster output that represents solar radiation (in watts per hour per square meter). During the analysis, the desired year and hour interval were specified to refine accuracy. Additionally, topographic parameters such as calculation direction were adjusted; for instance, setting 32 directions ensures that each cell is checked from 32 different angles for potential obstructions. To simplify the final readings, the raster output was divided by 1000, converting the values to kilowatts per hour per square meter, making the data more manageable and interpretable. The (figure-2) map was generated using ArcGIS which shows the solar potential of Islamabad. As seen in figure-2, most of Islamabad has high solar potential whereas some areas in the north near Margalla hills have moderate solar potential.

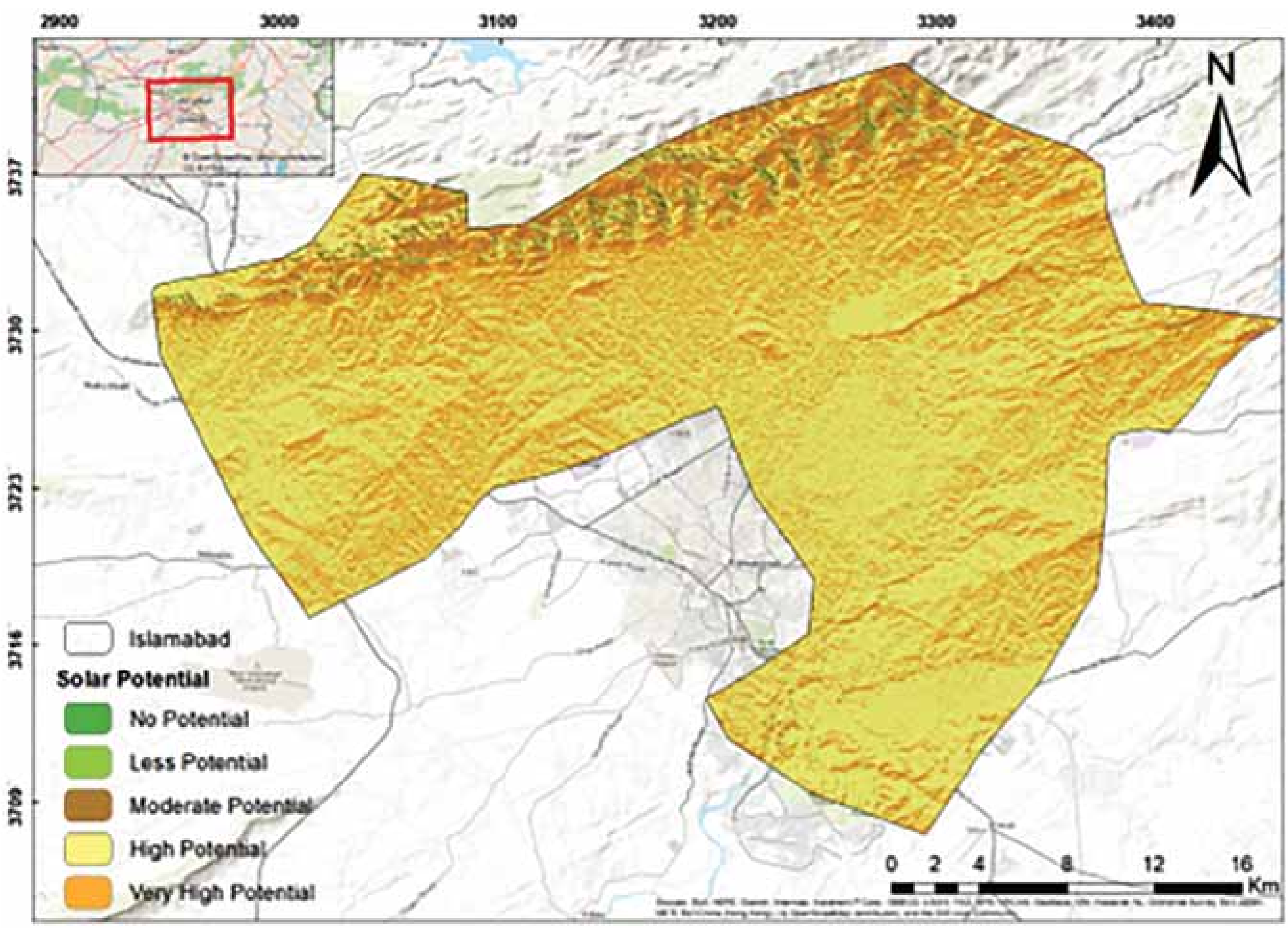


Figure-2: Solar potential in Islamabad..

Low Flood Risk

To identify the most suitable sites for installing electric vehicle charging stations, the study prioritized eliminating flood-prone areas. Flood susceptibility is influenced by natural features such as low-lying terrain and proximity to water bodies (rivers, lakes, or oceans), (Bunmi, et. al., 2022) as well as structures like dams or water reservoirs, which can fail and trigger flooding. To assess flood risk, we utilized the ArcGIS Hydrology tool extension. The following factors are basic in a flood risk assessment.

Influential factors in flood risk assessment;

- Elevation
- Slope
- Land use/land cover
- Precipitation
- Proximity to streams/channels

The process began with loading essential datasets such as Digital Elevation Model (DEM), slope, land cover, and precipitation, followed by generating a hill-shade map for better terrain visualization. After this the hydrological analysis (Kamal, 2004) was conducted which included fill, flow direction, flow accumulation, and stream extraction, to determine proximity to water channels. After this the study reclassified all layers, assigning ratings and scores based on flood susceptibility. Finally, by applying a weighted sum approach (see table- 2), a comprehensive flood risk map (see figure- 3) was produced, ensuring that charging station locations are placed in low-risk areas for long-term sustainability and safety. As seen in figure-3, areas marked in grey and light blue are not prone or slightly prone to flooding.

Table 2: Weights for hydrological analysis.

FACTORS	INFLUENCES
Elevation	10%
Slope	15%
Land use/ landcover	10%
Precipitation	35%
Proximity to streams/channels	30%

Land Use and Land Cover

Land cover and land use provide critical information for determining a site's viability for a certain use or development, and their examination can assist uncover prospective development obstacles or possibilities. Land cover and land use can also have an influence on a site's socioeconomic circumstances, (Zafar, 2014) such as access to infrastructure, housing, and services. For example, urban regions often have better access to infrastructure and

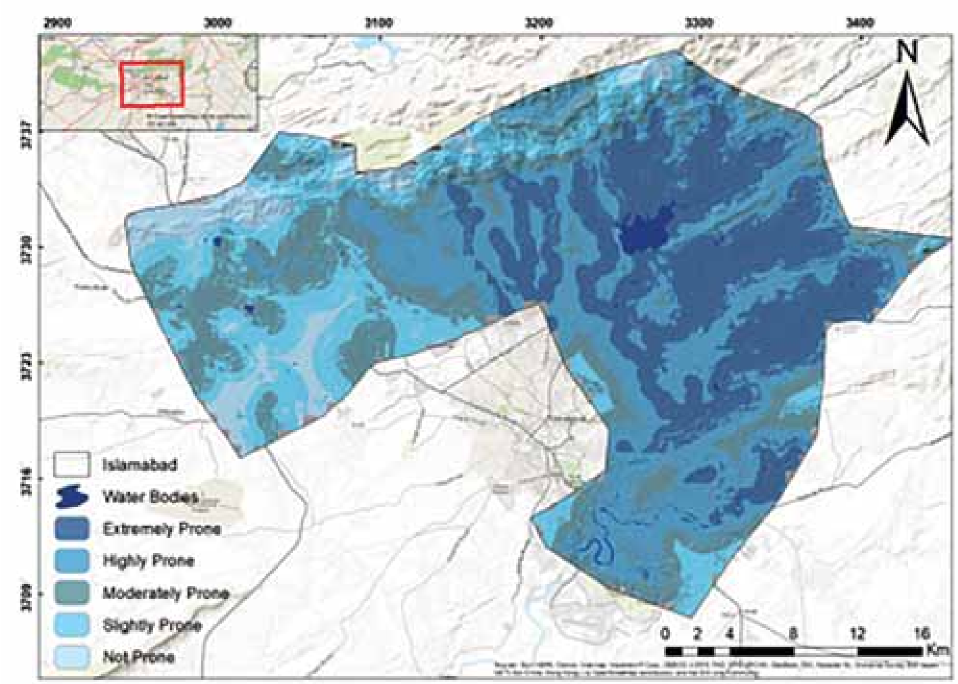


Figure-3: Flood risk in Islambad.

services than rural locations. In this study, the land use and land cover of Islamabad were divided into five classes: water bodies, shrubs, bare land, buildup area, and forest. These classes help us identify the potential zones for the installation of charging stations. ArcGIS was used to develop the land use map of Islamabad. As seen in (figure-4), areas in brown and yellow are built up areas or barren land whereas the rest of land is either shrubs, forest or water bodies.

Existing Parking Areas and Fuel Stations

Islamabad is experiencing rapid urban growth, resulting in high land costs, making efficient land utilization crucial. This study focuses on leveraging existing fuel stations and parking areas to enhance cost efficiency by utilizing pre-existing infrastructure. To map these locations, Google Earth Pro was used to manually digitize fuel stations and parking areas across the city (see figure- 5). Utilizing these

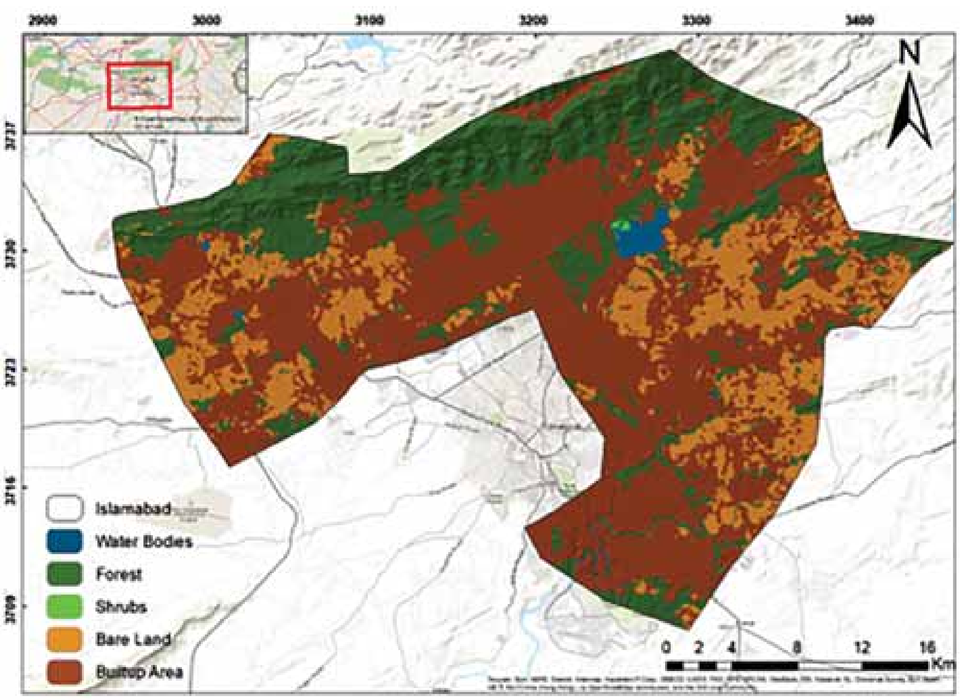


Figure-4: Land use and land cover of Islamabad.

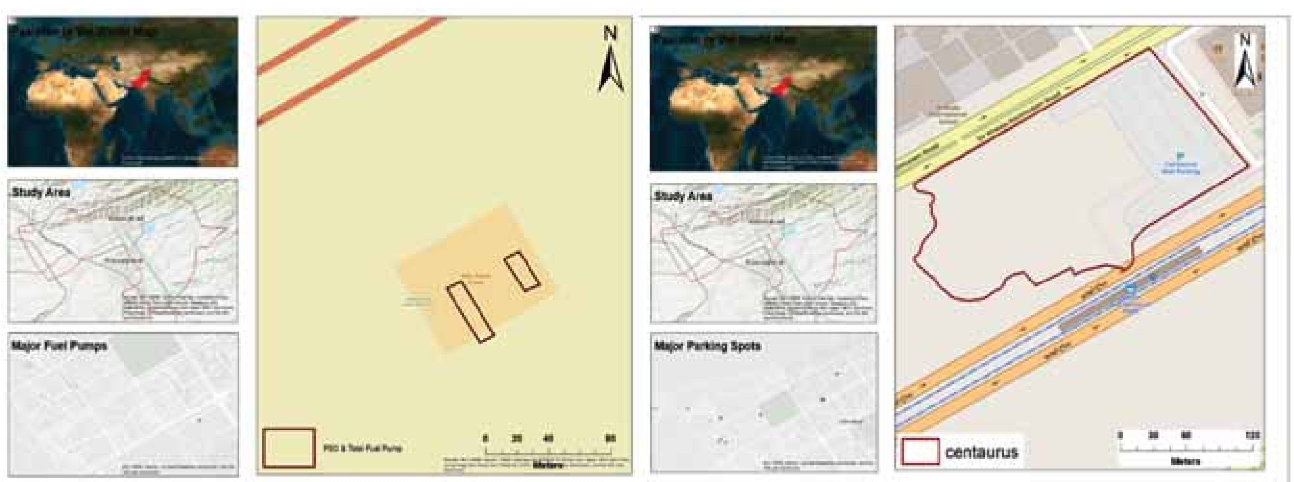


Figure-5: Existing parking spaces and fuel stations in Islamabad.

existing structures offers several advantages. They are strategically located near major roads, ensuring easy accessibility for vehicles. Additionally, installing charging stations at conventional fuel stations is feasible, as they already provide ample parking space. Furthermore, fuel station rooftops and parking areas possess significant solar potential, aligning with the study's emphasis on renewable energy integration.

Primary Roads

For charging stations to be effective, they must be easily accessible, and highways play a crucial role in ensuring convenient access for consumers. Without proper road connectivity, reaching charging stations would be challenging. This study focuses on identifying locations along Islamabad's primary roads to optimize accessibility (Haider, et. al., 2021). The dataset used for this analysis was obtained from OpenStreetMap (OSM). In ArcGIS, the data was filtered using the "Select by Attribute" tool to extract relevant road information. Since roads are a key determinant in site selection, their influence on the final results is significant. As seen in (figure- 6), highly suitable areas are marked in light cream color. Any areas in a 1km radius from these locations are optimal for electric vehicle charging stations.

Slope of Terrain

Slope is a crucial factor in this analysis, as it varies across Islamabad's terrain. While the central areas of the city are relatively flat, the hilly regions feature steep slopes. To assess suitability for EV charging stations (EVCSs), the slope range was categorized into five classes, from most suitable to least suitable. Slope plays a vital role in site selection, influencing drainage, accessibility, construction costs, (Jung, Han and kim, 2019) and environmental impact, making it an essential consideration for sustainable and efficient infrastructure development.

Solar Aspect

Another important topographic characteristic considered in this study is solar aspect, which determines the amount of sunlight a slope receives. Since the goal is to identify optimal sites for charging stations with maximum solar potential, aspect ratio plays a crucial role. Closely related to slope, aspect significantly influences the results of the analysis. For this study, Islamabad's aspect was categorized into five classes, ranging from most suitable to least suitable, with the objective of identifying areas that receive maximum sunlight throughout the day. According to ARGIS analysis, (see figure- 7) areas marked in green are highly suitable whereas, areas in yellow are also suitable.

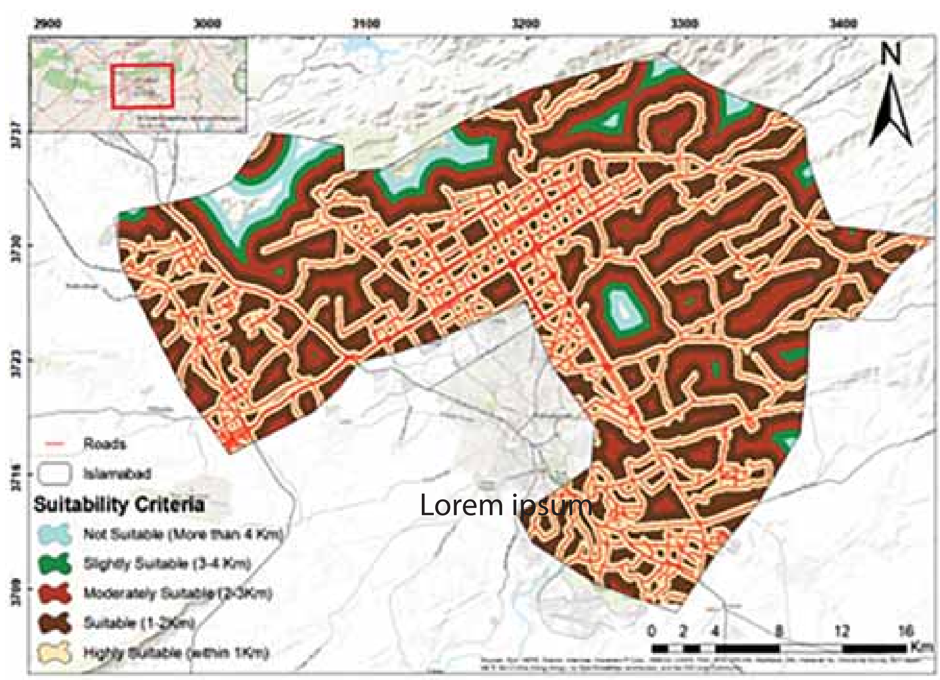


Figure-6: Primary road network in Islamabad.

Elevation

Islamabad's elevation ranges from approximately 450 meters (1,476 feet) to 1,600 meters (5,249 feet) above sea level, with an average elevation of 540 meters (1,770 feet). Elevation is a critical factor in the construction and (Huber, et, al., 2017) accessibility of charging stations, as well as in the overall design of the infrastructure. For this study, Islamabad's elevation was categorized into five classes, ranging from most suitable to least suitable, to ensure optimal site selection for charging stations. As seen in (figure- 8) areas marked in grey and light blue are suitable.

Site Suitability Analysis: Analytical Hierarchy Process (AHP) and Weighted Overlay

After acquiring all the necessary layers and datasets, the Analytic Hierarchy Process (AHP) was employed to compute the weights of each criterion. AHP is a structured decision-making technique that integrates mathematical modeling and psychological analysis to evaluate complex problems. The process begins by clearly defining the problem and identifying the relevant criteria. A decision hierarchy is then created, breaking the problem into smaller, more manageable segments. The top level of the hierarchy represents the overall goal, while the lower levels consist of decision criteria and alternative options. A pairwise comparison is conducted, (Yudhistira, et. al., 2023) where each criterion is evaluated relative to the others. In AHP (analytical hierarchy process), Saaty's scale (1–9) is used, where 1 signifies equal importance and 9 indicates extreme importance. After comparing each criterion, a comparison matrix is generated, and relative weights are computed by normalizing the values and summing them for each criterion. To ensure accuracy, a consistency check is performed to verify that the pairwise comparisons do not contain discrepancies or logical inconsistencies. Once the relative weights pass this check, each alternative is evaluated by multiplying the weight (Kaya, et. al., 2022) of each criterion by its respective performance score. The final decision is based on the alternative with the highest overall score (see table-3). In this study, seven factors were considered in the AHP model to determine the weights for site selection.

The weighted overlay is a widely used GIS analysis technique that integrates multiple spatial datasets into a single output layer based on their relative importance and interactions. This method employs a series of weights and mathematical functions (Rane, et. al., 2023) to combine input datasets in a weighted, nonlinear manner. In this analysis, weights were assigned to each layer according to their significance in the decision-making process. Since datasets often have different units and value ranges,

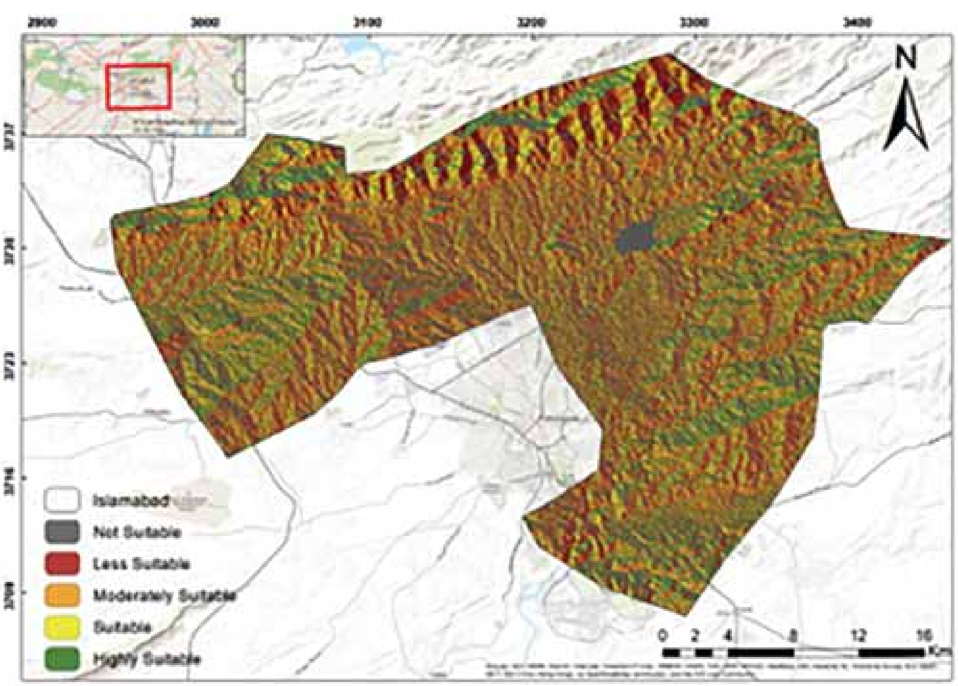


Figure-7: Solar aspect in Islamabad.

normalization was essential to ensure consistency. To achieve this, a common Likert scale ranging from 1 to 5 was defined, where 1 represented the most suitable areas and 5 the least suitable. Once the data were normalized and weights assigned, all layers were combined using the weighted overlay function. This tool generated a new output layer that depicted the overall suitability or risk assessment for decision-making. The results of this process provided a well-balanced and logical outcome for site selection analysis. (Figure- 9) shows the site suitability analysis flow chart that clearly explains the process from start to end. The final suitability map is shown in (figure-11) in the discussions section of this study.

Mobile Application Development

A key aspect of this study was developing a mobile application with a user-friendly, sophisticated, and visually appealing interface. The objective was to design a front-end that effectively represents the project's core mission—reducing CO_2 emissions and enhancing air quality. The image below (figure- 10) shows the user interface of the mobile application that was created to reduce range anxiety and allow users to find charging stations easily. The interface was crafted to ensure seamless user interaction (Hannan, et. al., 2022) while conveying the project's environmental impact and sustainability goals.

Table 3: Weighted overaly of different factors.

LAYERS	WEIGHTS
Land use and land cover	37.4
Solar potential/ Radiation	14
Roads	22.6
Flood	3.8
Slope	10.2
Elevation	7.3
Aspect	4.7

Packages and Libraries

The development of the application relied on several essential packages and libraries, each playing a crucial role in enhancing its functionality and performance. At the core of the applications development were Expo, React, and React Native. Expo provided a comprehensive development environment with tools and services for building React Native applications, while React allowed for the creation of reusable UI components. React Native, in turn, enabled the development of cross-platform mobile applications that could run seamlessly (Gülcüoğlu, et. al., 2021) on both iOS and Android. For user interface consistency and customization, Expo-status-bar ensured a

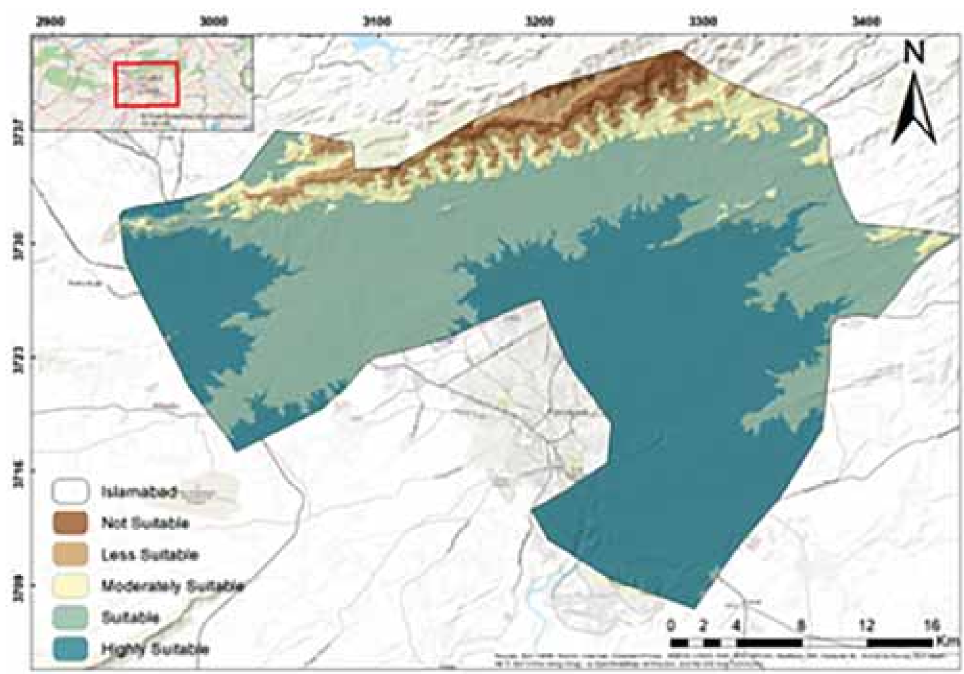


Figure-8: Elevation of areas in Islamabad.

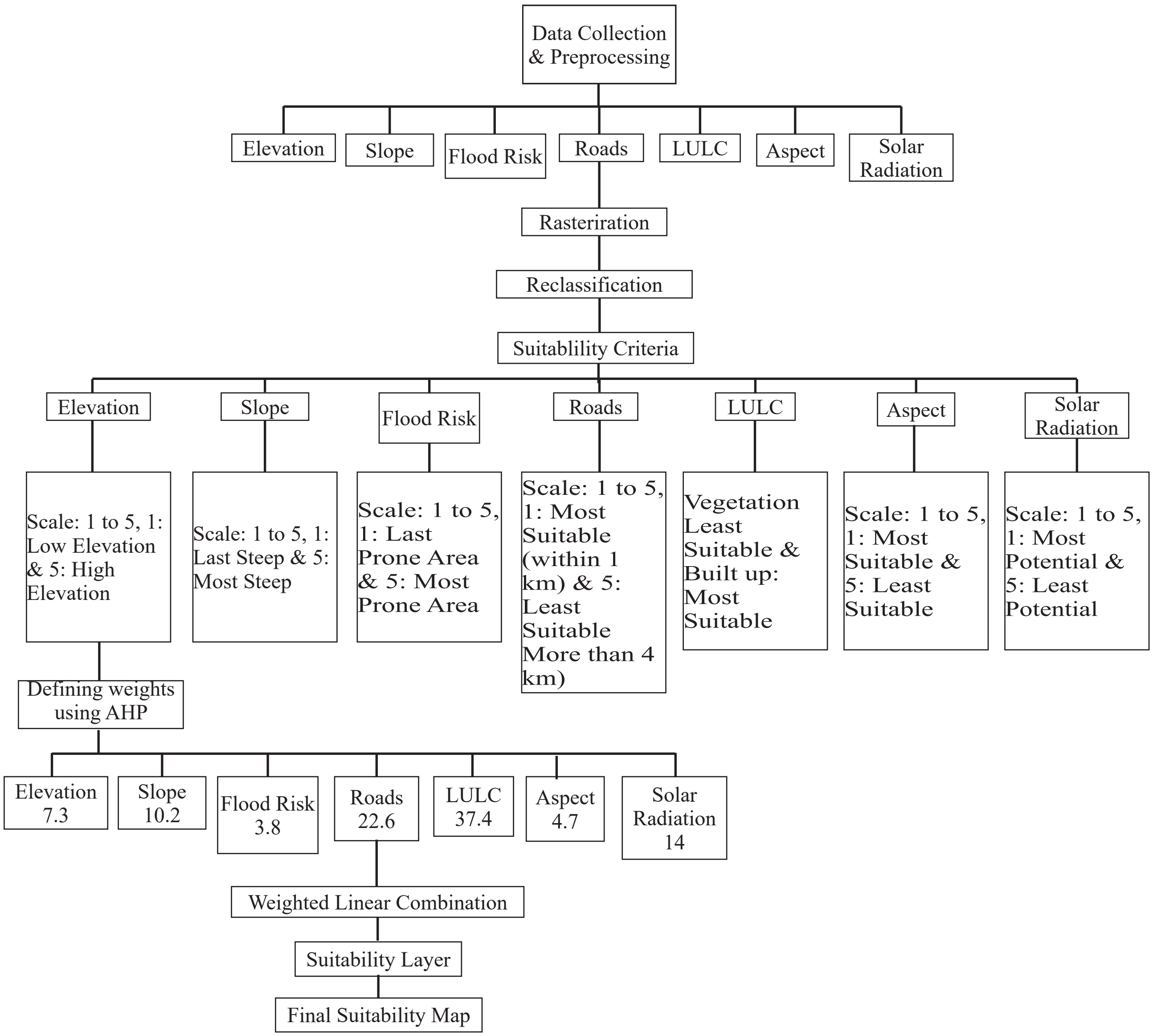


Figure-9: Site suitability analysis flowchart.

uniform status bar appearance across platforms, allowing developers to modify its color, background, and visibility. Additionally, @expo/vector-icons provided a wide range of customizable icons, improving the visual appeal and usability of the application.

Authentication and security were handled through Firebase, which offered backend support for authentication, (Khawas and Shah, 2018) real-time database management, storage, and hosting. The @firebase/app library provided the core Firebase functionality, managing configurations and granting access to its services. To enhance authentication, @firebase/auth allowed for various login methods, including email/password and social logins. Additionally, Expo-app-auth and Expo-auth-session were utilized to implement OAuth2 authentication, ensuring secure and smooth login experiences through providers such as Google and Facebook. Moreover, mapping and location services played a significant role in the application. React-native-maps enabled the integration of interactive maps, allowing users to view locations, markers, and overlays within the app. Expo-location further enriched the user experience by providing functions to obtain the device's real-time location, track movements, and calculate distances.

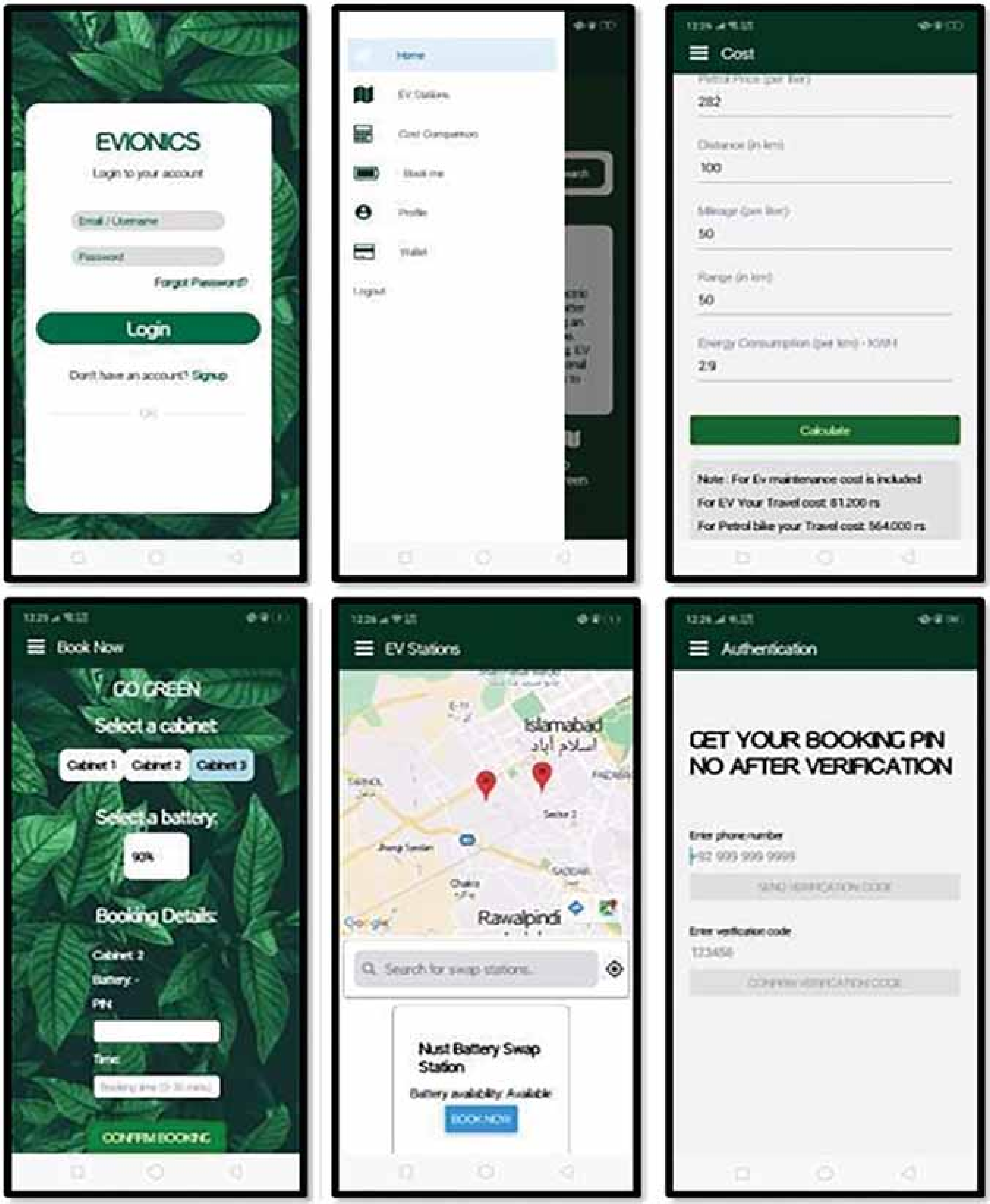


Figure-10: User interface of mobile application.

Efficient data handling and utility functions were supported by Prop-types, a runtime type-checking library ensuring correct React prop types, while Expo-random allowed the generation of random values, (Vorobchuk and Pashkevych, 2023) such as UUIDs and byte arrays. The Expo-constants library granted access to essential device-specific information, including operating system details and platform versions. Lastly, for web and deep-linking functionalities, Expo-linking facilitated deep linking, enabling users to open specific app screens directly from external sources like emails and websites. Expo-web-browser further enhanced this functionality by allowing the app to open URLs in the system’s default browser, supporting both deep linking and in-app browsing. To efficiently manage these dependencies and ensure smooth package handling, they were included in the "package.json" file. This approach allowed developers to install, update, and manage all necessary libraries efficiently within the Expo development environment, ensuring a seamless development process.

Discussion and Recommendations

The study’s findings confirm the potential for implementing sustainable EV (electric vehicle) infrastructure in Islamabad. Though this study was conducted in Islamabad where data was readily available however, similar spatial decision-making frameworks can also be adapted with proxy datasets or simplified weighting schemes to suit less data-rich environments. For this study, seven factors were considered to determine the most suitable locations for electric vehicle (EV) charging stations in Islamabad. Data from multiple reliable sources were utilized, and various geographic information system (GIS) preprocessing tools like ‘ArcGIS’ and techniques were employed to identify optimal sites. By integrating Analytic Hierarchy Process (AHP), Multi-Criteria Decision Analysis (MCDA), and GIS tools, the site suitability analysis provides a comprehensive and spatially explicit assessment, enabling stakeholders to make informed decisions regarding EV (electric vehicle) infrastructure deployment in the city. Once the factors and weights were carefully evaluated and assigned, each layer was reclassified to establish a suitability range, categorizing locations from most suitable to least suitable. Given Islamabad’s hilly terrain and varied topography; where the central area is situated at a lower elevation, (Tariq, et. al., 2021) while the northern and northeastern parts of the city gradually rise due to the Margalla Hills. The study findings show that areas of low elevation, high solar potential and low slope which allows more solar exposure are the most suitable in terms of solar potential. In the image above (see figure- 11) it can be seen clearly that the areas marked in green are most suitable whereas areas marked in yellow and red are least or not suitable at all because of their high elevation from sea level, low solar

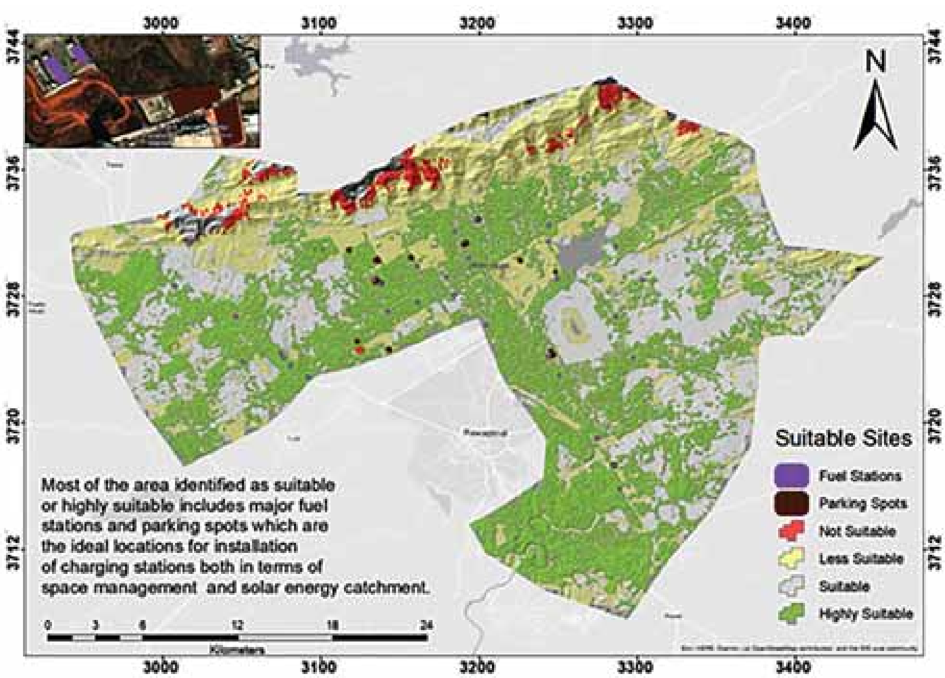


Figure-11: Suitable sites in Islamabad of charging stations.

exposure due to mountains and tree cover of Margalla hills. It is also imperative to mention here parking areas marked in brown and existing fuel stations marked in purple are also important sites to consider. Since property in Islamabad is already very expensive and scarce,(Hassan, et. al., 2016) it is important to consider these areas for creating electric vehicle solar powered charging stations. This will allow to cater space scarcity which a growing issue in Islamabad and maintain low carbon footprint as well. Solar aspect and low flood risk were also important parameters considered in the findings. Areas such as sector F-6, F-7, G-7 and sector G-8 which are areas closest to the CBD (central business district) (Hasan, et. al., 2021)are most suitable in terms of low flood risk and are also at low elevation and high solar exposure. This topographic variation indicates that the most suitable areas for charging stations are concentrated in this region of the city. Further analysis, along with insights from literature, also supports that these areas of Islamabad are the most favorable location for EV (electric vehicle) charging infrastructure because of their land use, close proximity to work spaces and other factors solidified in the GIS (geographic information system) analysis.

The GIS-based site selection provided valuable insights into optimal locations for charging stations while the mobile application serves as an efficient tool for users, alleviating range anxiety by allowing them to easily locate charging stations and book slots in advance. Another recommendation is that battery swapping could also be explored to improve efficiency (Deng, et. al., 2022) at these charging stations to allow for users to change batteries to reduce charge time and improve electric mobility experience. This will also be facilitating the change from ICEs to EVs (internal combustion engine to electric vehicles) and help the country reach its 2030 goal of having more electric cars in the country.

Though much of current focus in Pakistan is on private EV ownership in major cities, the shift to sustainable mobility must also include public transport, shared mobility, and the informal transport systems serving a broader community. Integrating EV technologies across these industries has the potential to greatly improve environmental performance while fostering economic inclusiveness. In addition, expanding EV infrastructure to rural and peri-urban regions, especially those supporting the movement of goods and people between production hubs and urban markets can also help offset current spatial and socio-economic disparities. Hence, EV planning approaches ought not only maximize technical appropriateness but also promote fair access and sustainable regional balance in mobility development.

CONCLUSION

Electric vehicles are gaining popularity in Pakistan however, changing from normal combustion engine cars to electric cars requires sustainable infrastructure, not just in terms of good roads and accessibility but also in terms of sustainable electric charging stations at optimal locations and suitable intervals. This study aimed at finding the most suitable location for electric vehicle charging stations with high solar potential as well as developing a user-friendly mobile application that would help locate these charging stations and allow users to book in advance and pay through the application. The main factors that were considered were solar potential, land use and land cover, existing parking spaces and existing fuel stations, slope, solar aspect, elevation from sea level and flood risk of all of Islamabad. For this process GIS (geographic information system) tool ARCGIS was used and a multi criteria decision analysis- AHP (Analytical Hierarchy Process) was conducted. The layers were laid on top of each other and weights were assigned to determine their importance and to the create a map that showed the site suitability of Islamabad for electric vehicle charging stations. This study successfully shows the possibility of creating sustainable charging infrastructure solution for electric vehicles in Islamabad by using GIS for site selection, and a user-friendly mobile application that allows ease in locating electric vehicle charging stations. These components together offer a comprehensive solution to enhance the adoption of electric vehicles in Islamabad. The study also showed that policymakers should prioritize the integration of renewable energy sources, like solar power, into electric vehicle charging infrastructure. It was also noted that the proposed mobile app should be regularly updated to provide real-time data. In this study, the most suitable areas for electric vehicle solar powered charging stations were existing fuel stations and parking lots and areas near the central business district. These are areas which had low flood risk, high solar exposure, high solar aspect, low elevation and were already equipped with existing supporting infrastructure. Future studies could explore scaling up the proposed solutions to other urban areas, with a focus on adapting them to meet the needs of various types of electric vehicles. This study recognizes the fast-paced nature of electric vehicle (EV) technology, battery technology, and competitive market forces that continue to transform the sustainable mobility landscape. In this context, the GIS-based suitability model and mobile application prototype proposed here are flexible tools that have the potential to keep up with new technological and market developments. The framework used in this study, has room for adaptation to include emerging parameters like improvements in battery efficiency, charging rates, and integration of renewable energy sources. Also, the methodology presents opportunities for extension using simulated or field-based research across diverse geographic and socio-economic contexts. Such uses can assist in optimizing spatial planning solutions, facilitate policymaking, and inform data-driven decision-making in future EV infrastructure development.

REFERENCES

Abro, A. A., Bano, S., Tariq, U. & Shah, I. A. (2022). Sun Tracking and Control Design for PV Solar energy system. *International Journal of Innovations in Science and Technology*. https://doi.org/10.33411/ijist/2022040507

Abro, G. E. M., Zulkifli, S. A. B. M., Kumar, K., El Ouanjli, N., Asirvadam, V. S. & Mossa, M. A. (2023). Comprehensive Review of Recent Advancements in Battery Technology, Propulsion, Power Interfaces, and Vehicle Network Systems for Intelligent Autonomous and Connected Electric Vehicles. *Energies*. https://doi.org/10.3390/en16062925

Adem Esmail, B. & Geneletti, D. (2018). Multi-criteria decision analysis for nature conservation: A review of 20 years of applications. *Methods in Ecology and Evolution*. https://doi.org/10.1111/2041-210X.12899

Ahmed, M. A., El-Sharkawy, M. R. & Kim, Y. C. (2020). Remote monitoring of electric vehicle charging stations in smart campus parking Lot. *Journal of Modern Power Systems and Clean Energy*. https://doi.org/10.35833/MPCE.2018.000502

Ashraf Javid, M., Ali, N., Abdullah, M., Campisi, T. & Shah, S. A. H. (2021). Travelers' Adoption Behavior towards Electric Vehicles in Lahore, Pakistan: An Extension of Norm Activation Model (NAM) Theory. *Journal of Advanced Transportation*. https://doi.org/10.1155/2021/7189411

Asim, M., Usman, M., Abbasi, M. S., Ahmad, S., Mujtaba, M. A., Soudagar, M. E. M. & Mohamed, A. (2022). Estimating the Long-Term Effects of National and International Sustainable Transport Policies on Energy Consumption and Emissions of Road Transport Sector of Pakistan. *Sustainability (Switzerland)*. https://doi.org/10.3390/su14095732

Bathla, G., Bhadane, K., Singh, R. K., Kumar, R., Aluvalu, R., Krishnamurthi, R., Kumar, A., Thakur, R. N. & Basheer, S. (2022). Autonomous Vehicles and Intelligent Automation: Applications, Challenges, and Opportunities. *Mobile Information Systems*. https://doi.org/10.1155/2022/7632892

Bunmi Mudashiru, R., Sabtu, N., Abdullah, R., Saleh, A. & Abustan, I. (2022). Optimality of flood influencing factors for flood hazard mapping: An evaluation of two multi-criteria decision-making methods. *Journal of Hydrology*. https://-doi.org/10.1016/j.jhydrol.2022.128055

Danielsson, W. (2016). *React Native application development*. Linköpings Universitet.

Deng, Y., Mu, Y., Dong, X., Wang, X., Zhang, T. & Jia, H. (2022). Coordinated operational planning for electric vehicles considering battery swapping and real road networks in logistics delivery service. *Energy Reports*. https://doi.org/10.1016/j.-egyr.2021.11.185

Duan, W., Khurshid, A., Nazir, N. & Calin, A. C. (2022). Pakistan's energy sector—from a power outage to sustainable supply. Examining the role of China–Pakistan economic corridor. *Energy and Environment*. https://doi.org/10.1177/0958305X211044785

Erbaş, M., Kabak, M., Özceylan, E. & Çetinkaya, C. (2018). Optimal siting of electric vehicle charging stations: A GIS-based fuzzy Multi-Criteria Decision Analysis. *Energy*. https://doi.org/10.1016/j.energy.2018.08.140

Government of Pakistan. (2020). *Pakistan Bureau of Statistics*. Pakistan Bureau of Statistics.

Gülcüoğlu, E., Ustun, A. B. & Seyhan, N. (2021). Comparison of Flutter and React Native Platforms. *Journal of Internet Applications and Management*. https://doi.org/10.34231/iuyd.888243

Haider, F., Rehman, Z. U., Khan, A. H., Ilyas, M. & Khan, I. (2021). Performance evaluation of BRT standard in decision support system for integrated transportation policy. Sustainability (Switzerland). https://doi.org/10.3390/su13041957

Haider, S. A., Sajid, M. & Iqbal, S. (2021). Forecasting hydrogen production potential in islamabad from solar energy using water electrolysis. *International Journal of Hydrogen Energy*. https://doi.org/10.1016/j.ijhydene.2020.10.059

Hannan, M. A., Mollik, M. S., Al-Shetwi, A. Q., Rahman, S. A., Mansor, M., Begum, R. A., Muttaqi, K. M. & Dong, Z. Y. (2022). Vehicle to grid connected technologies and charging strategies: Operation, control, issues and recommendations. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2022.130587

Hasan, L., Chaudhry, A., Ahmad, A. & Jalil, H. (2021). Slums, Sprawl and Contemporary Islamabad - A Doxiadis' Mess. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3885118

Hassan, Z., Shabbir, R., Ahmad, S. S., Malik, A. H., Aziz, N., Butt, A. & Erum, S. (2016). Dynamics of land use and land cover change (LULCC) using geospatial techniques: a case study of Islamabad Pakistan. *Springer Plus*. https://-doi.org/10.1186/s40064-016-2414-z

Huber, N., Hergert, R., Price, B., Zäch, C., Hersperger, A. M., Pütz, M., Kienast, F. & Bolliger, J. (2017). Renewable energy sources: conflicts and opportunities in a changing landscape. *Regional Environmental Change*. https://-doi.org/10.1007/s10113-016-1098-9

Ibrahim, N. I. L., Ariffin, M. M. & Zakariya, A. (2022). Mobile Application of Data Visualization for Electric Vehicle. 6th *International Conference on Computing, Communication, Control and Automation, ICCUBEA 2022*. https://-doi.org/10.1109/ICCUBEA54992.2022.10010927

Jung, J., Han, S. U. & Kim, B. (2019). Digital numerical map-oriented estimation of solar energy potential for site selection of photovoltaic solar panels on national highway slopes. *Applied Energy*. https://doi.org/10.1016/j.apenergy.2019.03.101

Kadrija, S., Memeti, A. & Luma-Osmani, S. (2022). Development of mobile app through React Native hybrid framework. 1*1th Mediterranean Conference on Embedded Computing, MECO 2022*. https://doi.org/10.1109/MECO55406.2022.9797173

Kaluza, M. & Sierpinski, G. (2019). Procedures for the Actions Required to Build Electric Car Charging Stations Against the Polish Legal Framework. *Scientific Journal of Silesian University of Technology*. Series Transport. https://doi.org/10.20858/sj-sutst.2019.105.8

Kamal, A. (2004). Pakistan: Lai Nullah Basin Flood Problem Islamabad-Rawalpindi Cities. *WMO/GWP Associated Programme on Flood Management*.

Kanwal, S., Mehran, M. T., Hassan, M., Anwar, M., Naqvi, S. R. & Khoja, A. H. (2022). An integrated future approach for the energy security of Pakistan: Replacement of fossil fuels with syngas for better environment and socio-economic development. *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2021.111978

Kaya, Ö., Alemdar, K. D., Atalay, A., Çodur, M. Y. & Tortum, A. (2022). Electric car sharing stations site selection from the perspective of sustainability: A GIS-based multi-criteria decision making approach. *Sustainable Energy Technologies and Assessments*. https://doi.org/10.1016/j.seta.2022.102026

Khawas, C. & Shah, P. (2018). Application of Firebase in Android App Development-A Study. *International Journal of Computer Applications*. https://doi.org/10.5120/ijca2018917200

Khurana, A., Kumar, V. V. R. & Sidhpuria, M. (2020). A Study on the Adoption of Electric Vehicles in India: The Mediating Role of Attitude. *Vision*. https://doi.org/10.1177/0972262919875548

Mahboob, K., Tanveer, S., Awais, Q., Khan, A., Zahid, T., Naeem, F. Bin, Khalid, H. & Pakistan, G. (2021). Economic and Environmental Effects of Plugin Hybrid and Electric Cars in Pakistan. *Pakistan Journal of Engineering and Technology*, PakJET.

Martins, L. S., Guimarães, L. F., Botelho Junior, A. B., Tenório, J. A. S. & Espinosa, D. C. R. (2021). Electric car battery: An overview on global demand, recycling and future approaches towards sustainability. *Journal of Environmental Management*. https://doi.org/10.1016/j.jenvman.2021.113091

Mouhy-Ud-Din, M. A., Azeem, F., Memon, Z. & Arshad, J. (2024). Comparative techno-economic assessment of electric vehicle charging preferences: A quantitative study for sustainable EV policy in Pakistan. *Energy for Sustainable Development.* https://doi.org/10.1016/j.esd.2023.101355

Nadeem, A., Rossi, M., Corradi, E., Jin, L., Comodi, G. & Nadeem, A. S. (2022). Energy-Environmental Planning of Electric Vehicles (EVs): A Case Study of the National Energy System of Pakistan. *Energies*. https://doi.org/10.3390/en15093054

Parikh, A., Shah, M. & Prajapati, M. (2023). Fuelling the sustainable future: a comparative analysis between battery electrical vehicles (BEV) and fuel cell electrical vehicles (FCEV). *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-023-26241-9

Rajagopalan, A., Swaminathan, D., Bajaj, M., Damaj, I., Rathore, R. S., Singh, A. R., Blazek, V. & Prokop, L. (2024). Empowering power distribution: Unleashing the synergy of IoT and cloud computing for sustainable and efficient energy systems. *Results in Engineering*. https://doi.org/10.1016/j.rineng.2024.101949

Rane, N. L., Achari, A., Saha, A., Poddar, I., Rane, J., Pande, C. B. & Roy, R. (2023). An integrated GIS, MIF, and TOPSIS approach for appraising electric vehicle charging station suitability zones in Mumbai, India. *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2023.104717

Sankaran, G. & Venkatesan, S. (2022). Growth of Battery Swapping in EV Passenger Car Segments in India. *International Journal of Vehicle Structures and Systems*. https://doi.org/10.4273/ijvss.14.1.26

Shakeel, U. (2022). Electric vehicle development in Pakistan: Predicting consumer purchase intention. *Cleaner and Responsible Consumption*. https://doi.org/10.1016/j.clrc.2022.100065

Sierra, A. & Reinders, A. (2021). Designing innovative solutions for solar-powered electric mobility applications. *Progress in Photovoltaics: Research and Applications*. https://doi.org/10.1002/pip.3385

Tariq, A., Shu, H., Siddiqui, S., Mousa, B. G., Munir, I., Nasri, A., Waqas, H., Lu, L. & Baqa, M. F. (2021). Forest fire monitoring using spatial-statistical and Geo-spatial analysis of factors determining forest fire in Margalla Hills, Islamabad, Pakistan. *Geomatics, Natural Hazards and Risk*. https://doi.org/10.1080/19475705.2021.1920477

Taub, E. (2017). For Electric Car Owners, 'Range Anxiety' Gives Way to 'Charging Time Trauma' - *The New York Times*. New York Times .

Tavana, M., Soltanifar, M. & Santos-Arteaga, F. J. (2023). Analytical hierarchy process: revolution and evolution. *Annals of Operations Research.* https://doi.org/10.1007/s10479-021-04432-2

Ullah, Z., Wang, S., Wu, G., Hasanien, H. M., Rehman, A. U., Turky, R. A. & Elkadeem, M. R. (2023). Optimal scheduling and techno-economic analysis of electric vehicles by implementing solar-based grid-tied charging station. *Energy*. https://doi.org/10.1016/j.energy.2022.126560

Vorobchuk, M. & Pashkevych, K. (2023). DIGITAL CODE AS AN OBJECT GRAPHIC DESIGN FOR DISSEMINATION AND PROMOTION OF BRAND. Art History and Criticism. https://doi.org/10.2478/mik-2023-0010

Wahid, F., Ullah, H., Ali, S., Jan, S. A., Ali, A., Khan, A., Khan, I. A. & Bibi, M. (2021). The determinants and forecasting of electricity consumption in Pakistan. *International Journal of Energy Economics and Policy*. https://doi.org/10.32479/ijeep.10646

Wang, X., Xia, W., Yao, L. & Zhao, X. (2024). Improved Bayesian Best-Worst Networks With Geographic Information System for Electric Vehicle Charging Station Selection. *IEEE* Access. https://doi.org/10.1109/ACCESS.2023.3347037

Yudhistira, Y., Pratama, D. A., Sandro, A., Rifai, B. & Azis, M. A. (2023). Decision Support System For Electric Car Selection Using AHP and SAW Methods. *Journal of Mantik*. https://doi.org/https://doi.org/10.35335/mantik.v7i2.4011

Zafar, S. M. (2014). Spatio-temporal analysis of land cover/land use changes using geoinformatics (A case study of Margallah Hills National Park). *Indian Journal of Science and Technology*. https://doi.org/10.17485/ijst/2014/v7i11.23

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING
Volume 35 Issue 2
ISSN (P) 1728-7715 - ISSN (E) 2519-5050
Journal DOI: www.doi.org/10.53700/jrap_neduet
Issue DOI: www.doi.org/10.53700/jrap3522025

IDENTIFYING, QUANTIFYING AND CLASSIFYING URBAN VOIDS OF ISLAMABAD, PAKISTAN

Rabbia Tanveer*

Article DOI:
www.doi.org/10.53700/jrap3522025_4

Article Citation:
Tanveer, R., 2025, Identifying, Quantifying and Classifying Urban Voids of Islamabad, Pakistan, *Journal of Research in Architecture and Planning,* 35(2). 55-73.

* Lecturer, National College of Arts, Rawalpindi.
rabbia.tanveer@nca.edu.pk
ORCID: 0000-0002-5223-2597

ABSTRACT

Islamabad, unlike other renowned cities such as Brasilia, Florence, Santa Fe, Venice, New York, and Istanbul, lacks distinctive architectural drama, cultural preservation, sensory stimulation, splendor, vibrancy, and visual extravagance. Since its inception, Islamabad has often been described as a 'dead city',. This is a perception that is heightened by the excessiveness of voids in the city. A void is an empty, abandoned, threatening space that is desolated by its very structural properties. However, it can be viewed as a new form of asset to a community, one in which it generates value and opportunities of its own for reinvestment and reconfiguration in light of contemporary lines of social, economic, and environmental desires. They may exist to support ecosystem services, especially to optimize benefits and enhance them for indigenous groups. It is necessary to restore urban voids, perceiving them as "spaces of potentiality". This will be accomplished by calculating their quantity and understanding their source of development. In this context, the study uses a descriptive research method, as well as observational and survey data, and finds that there are a total of 282 spacious remaining urban voids spanning 158,971,182 sqft, which constitute 23.15% of the city's territory. This will provide a valuable contribution to revitalizing the city's cultural heritage and social life.

Keywords: Urban void, vacant lots, terrain vagues, Islamabad.

INTRODUCTION

Islamabad, the purpose-built capital of Pakistan, was conceived as a symbol of modernity and progress, designed to reflect the aspirations of a newly independent nation. (Quaiyoom, 1997, p. 15). Yet, over the decades, this meticulously planned city has earned the unsettling tag of a "dead city"—a place where the vibrancy and cultural richness found in other capitals are conspicuously absent. The city's master plan, while ambitious, inadvertently created vast expanses of underutilized and abandoned spaces, now referred to as urban voids. These voids, rather than contributing to the city's architectural grandeur or social fabric, have become stark reminders of planning inefficiencies and socio-political disconnects.

Urban voids in Islamabad are not merely empty spaces; they are symptomatic of a deeper, more complex urban malaise. These spaces disrupt the city's cohesion, hinder social interaction, and, in many cases, pose environmental and safety risks (Tapner 1977) .The challenge lies not just in the physical presence of these voids, but in what they represent; missed opportunities for community building, cultural expression, and sustainable urban growth.

This research seeks to systematically identify, quantify, and classify these urban voids within Islamabad, with the aim of transforming them from symbols of neglect into catalysts for urban revitalization. By focusing on Islamabad, this study addresses a critical gap in urban planning literature, offering insights that are both contextually relevant and universally applicable. Understanding and repurposing these voids is not only essential for the city's sustainable future but also for reimagining its identity as a vibrant, living urban center.

URBAN VOIDS DEFINITION

The term "urban void" is probably one of the best ways to describe an area that serves no purpose. This term refers to a space that remains unclaimed and underutilized, disrupting the carefully planned uniformity of urban premises and structures. In some cases, these spaces are referred to as "urban ruins" because they should be eliminated as soon as they are discovered - voids have no permeability to speak of, nor do they have any socialization within their boundaries by definition, making them completely useless and undesirable spaces (Aporee, 2011). Because they do not share borders with other setups and do not blend in with the surrounding space, they do not contribute positively to the overall ambiance and experience that a city can provide to visitors and citizens (Oswalt et al., 2006). Strong urban blocks, on the other hand, are directly connected to the street network and open spaces (Trancik, 1986, Secchi, 1993).

URBAN VOIDS CLASSIFICATION

Northam (1971) categorized urban voids into five types (figure 1). His work also identified a number of factors

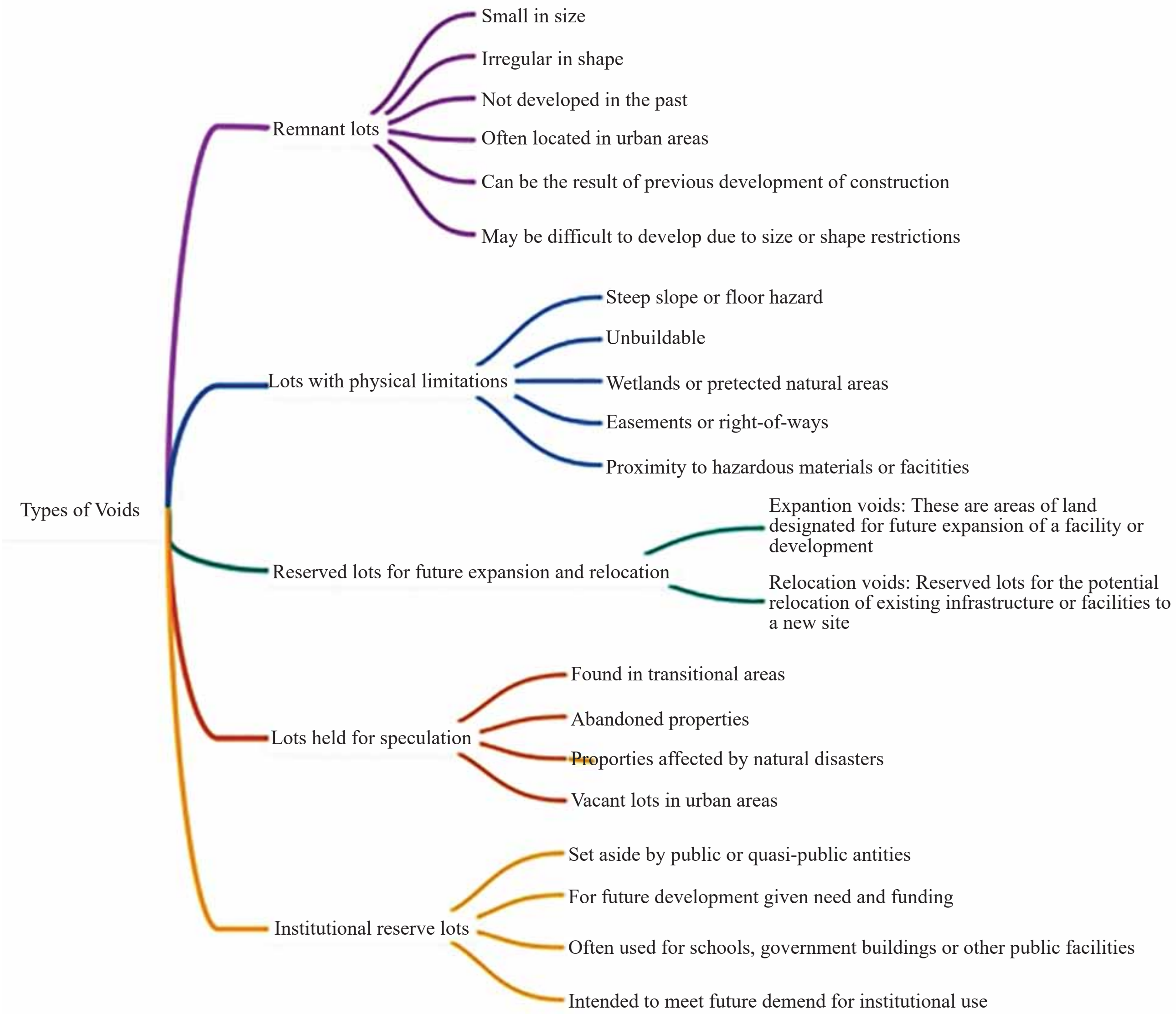


Figure-1: Types of voids (Author Generated).

contributing to the emergence of urban voids, which can also serve as the basis of a more complete classification of such territories. This study will focus on three types:

1 Planning Voids
2 Functional Voids
3 Geographical Voids

Planning Voids

Planning voids are created due to improper and inefficient isolated planning processes, where the overall city fabric is ignored. These voids often result from fragmented urban planning that fails to consider the holistic integration of urban spaces. Planning voids are the most noticeable in our urban communities and can be identified using the figure ground theory, which highlights the unintentional open spaces left between built structures.

Functional Voids

Functional voids consist of leftover spaces or built structures that have become superfluous. These voids emerge when certain urban elements become redundant due to changes in urban needs, such as outdated infrastructure or obsolete buildings. Functional voids often have a legal perspective attached, as they typically involve structures or lots that are under litigation or public ownership. The bureaucratic process for reallocating these functions can be lengthy and tedious, often leaving these areas unused for extended periods.

Geographical Voids

Geographical voids are existing topographical features within urban areas that become voids when planners and architects fail to respond effectively to them. These voids occur around natural geographies, such as rivers, streams (nallahs), or other landscape features, which are not adequately integrated into the urban layout. As a result, these spaces become unusable or underutilized, representing a missed opportunity to enhance the urban environment.

These frameworks not only classify urban voids but also create a picture of the time they may exist, their origin, and the problems that can potentially arise in connection with them. Understanding the nature of urban voids is essential for planning and developing the places that are considered wasted.

Urban Voids in Literature

Urban voids, also called wastelands, margins, derelict areas, residuum, no man's land, spaces of uncertainty, dead zones, spatial obsolescence or interstitial spaces, have always been a concern of the people who study the urban environment. These terms reflect the idea of certain areas within cities that are abandoned and forgotten by the municipal government or simply put on hold to be used in the future. It is a rather multidisciplinary topic, which found its place in the spheres of urban studies, geography, sociology, and ecology. Below the existing literature connected with restricted space or urban voids is presented with the hands definitions of both what they are and what opportunities they seem to promise as far as the city environment regeneration and development of the community are concerned.

Historical Context and Evolving Definitions

The concept of urban voids has undergone a substantial transformation over time. Initially, it was regarded as an urban fabric or through other negative terms, such as neglect and decline. Lynch (1960) underscored the psychological significance of urban landscapes, which, in a sense, are influenced by unstructured spaces. The concept of "lost space" was introduced by Trancik (1986) to define the anti-spaces that are produced by modernist planning ideologies, which was the most significant framework for understanding these places. Many of Trancik's urban design projects, which were centered on functionality and efficiency, did not result in environments that were consistent with human life and relationships. Rather, they created voids in cities, which resulted in alienated spaces.

There exists a variety of definitions or discussions of the concept based on the authors’ or the perspectives of the cultural, geographical, or disciplinary areas. For example, according to Coleman (1982) and Jakle and Wilson (1992), the areas for the proposed urban voids, although to some extent, can be considered as focuses of activity in both texts. Those areas are referred to as "derelict land" or "dead spaces," which reflects their abandonedness and being non-utilized. In Mathey and Rink, the space under question is defined as a “wasteland” that can be recycled into a form of ecological inheritance (Mathey and Rink 2010). Hwang and Lee (2020) added more information on the theoretical basis of defining urban void space. They define urban void spaces as unused, underused, and misused space types in the urban field.

Historically, “urban void” has been a term widely associated with the concept of abandoned and dilapidated spaces in urban areas. However, De Girolamo (2013) re-conceptualizes "disused spaces" and underscores their potential for temporary reuse, which ultimately results in revitalized, vibrant, multi-functional locations that are ever-changing in accordance with the urban context. Thus, "urban voids" must be considered as innovative urban regeneration opportunities rather than exclusion or alienation.

Recent scholarship has expanded the understanding of what urban void is and included its social and ecological functions in an urban environment. A detailed social-ecological assessment of vacant lots in New York City was conducted by Kremer, Hamstead, and McPhearson (2013) to serve these roles. Rathi and Kushwah pointed out that "urban voids" may represent a place to be redeveloped, whereas Dhamal (2019) reviewed wastelands as “shared spaces” in Pimpri, Pune. Other research, such as studies by Hwang and Lee (2020), identified these spaces as "unused, underused or misused" and provided novel guidelines for their reinterpretation. Lopez-Pineiro (2020) further systematized it in his glossary, shedding light on ideas such as Terrain Vague and Buffer Zones along with Hashem WAHBA-Nasr-ELDIN (2022) that devoted their research towards its temporary architecture solution. Most recently, Aleha et al. (2023) Introduced the idea of "catalytic urban voids," arguing that they can close and mend social fractures. Table 1 represents a richer interpretation of urban voids, which presents a chronological summary of how this term was defined and also enriched over the last few decades.

Contemporary Research and Theoretical Frameworks

Current scholarship has begun to widen the conversation on empty spaces in cities and investigates an alternative approach that considers these places as flexible areas adaptable for a variety of uses. A prominent theoretical framework is the notion of "loose space," (Franck & Stevens, 2007). As Amin and Thrift put it in their pathbreaking text, Loose Space: Possibility and Diversity in Urban Life, loose spaces are under-regulated areas on account of being so ambiguous that they not only promote but practically necessitate improvisation, experimentation or socializing. These in-between spaces are the types that formal planning processes tend to overlook or misjudge and can be repurposed for temporary events, community meetings, and informal economies. This outlook undermines the orthodox system of urban planning by demanding and catering to an adaptive, accessible spatial deployment.

Elaborating upon this discussion, Dovey and Palka (2016) determines the concept of "urban porosity" as being about open urban spaces, voids, and the permeability and accessibility in urban. As they argue, urban voids can increase the speed at which people move through the city and interact with it since they are open areas without any formal structures. This idea fits within a larger urban policy that highlights the necessity for cohesive, accessible places (Dovey & Palka, 2016).

Research on temporary uses within urban voids has been rich in recent years. Lopez-Pineiro (2020) provides an extensive "Glossary of Urban Voids," in which he categorizes different kinds of voids and the possibilities they would allow. The examples within this work offer much insight.

Elmeligy' Arnouty and Ebrahim, (2024) explore the use of temporary architecture to reanimate vacant sites in Alexandria, demonstrating how temporary structures can facilitate cultural, social, and economic activities.

The notion of “temporary urbanism” has developed vigorously in our time as the majority of cities suffer from negative economic and demographic trends. Bishop and Williams (2012) provide an analysis of the “temporary city” in their book The Temporary City. Their major idea is that the temporary use of space will activate declining spaces and will help to involve the community. Temporarily, urbanism allows for the testing and piloting of new ideas and, thus, creates a possibility to avoid high costs, as in the case of failure, the process may cease. The example of Berlin, where temporary cultural spaces have utilized declining buildings, or Detroit, where unused lands were transformed into community gardens, may illustrate temporary urbanism.

Ecological and Environmental Perspectives

Urban voids’ ecological potential is an area of vital importance that needs further investigation. Voids that are present within the city and remain undisturbed may transform into a crucial part of the urban landscape as they have been hardly explored in that regard over the years. It was Mathey and Rink (2010) who drew attention to the possibility of urban biodiversity in the city. They believed

Table 1: Urban void definitions as per literature (author generated).

Year	Author (s)	Publication Name	Publication Type	Definition
1974	Sommer	Tight Spaces: Hard Architecture and how to humanize it	Book	Tight Space. Hard spaces
1986	Trancik	Finding Lost Spaces: Theories of Urban Design	Book	Lost Space
1996	Loukaitousideris	Addressing the constraints and potentials of urban design	Book	Cracks in the City
1996	Sola-Morales	Terrain Vague	Article	Terrain Vogue
2000	Paigona & Bowman	Vacant land in Cities: An urban Resource	Book	Vacant Land
2001	Hajer & Reijdorp	In search of a new public domain: analysis and strategy article	Article	In between sapces
2002	Nielsen	The return of the excessive: superfluous landscapes	Article	Superfluous landscape
2003	LaVarra	Post it city: the other European spaces	Article	Post-it city
2005	Clement			Delaissic
2005	Groth, Corjin	Reclaiming Urbanity: Indeterminate spaces, informal archotrs and urban agenda setting	Article	Inderminated space
2007	Worpole & Knox	The social value of Public spaces	Book	Slack space
2007	Franck and Stevens	Loose space: Possibility and diversity in urban life	Book	Loose space
2013	Peleg Kremer, Zoé A. Hamstead, Timon McPhearson	A social–ecological assessment of vacant lots in New York City	Journal Article	Vacant lots
2017	K. Rathi & N. Kushwah	Urban voids–reclaiming urban space	Journal Article	Urban voids
2017	Nilima Dhamal	Reimagining lost spaces in a city case of Pimpri, Pune	Doctoral Dissertation	Urban voids, shared spaces
2020	S. W. Hwang & S. J. Lee	Unused, underused, and misused: an examination of theories on urban void spaces	Journal Article	Unused, underused, and misused urban spaces
2020	Sergio Lopez-Pineiro	A Glossary of Urban Voids	Book	Urban Voids, Terrain Vague, Buffer Zones
2022	O. M. Hashem, S. M. Wahba, T. I. Nasr-Eldin	Temporary Architecture a study of Revitalizing Alexandria's Urban Voids	Journal Article	Optimized Urban Voids
2023	A. Aleha, S. M. Zahra, S. Qureshi, S. A. Marri, S. Siddique, S. S. Hussain	Urban void as an urban catalyst bridging the gap between the community	Journal Article	Catalytic Urban Voids

that such sites could be viewed as 'urban green islands', which would help to improve the quality of air and water consumption, maintain the right temperature, and serve as habitats for a variety of species.

Various researchers demonstrated that the significance of urban voids has been reconsidered in terms of urban resilience. Thus, according to Douglas, Lennon, and Scott (2017), spending a substantial part of the present study on urban green spaces and voids, inquire how these conservation elements could be employed to alleviate the possible deteriorating effects of climate change while preventing the occurrence of heat islands. In other words, the efficacious inclusion of the currently considered elements into the framework of urban planning is bound to turn its pivotal point and help create an ecologically sustainable model for a city.

Kremer, Hamstead, and McPhearson (2013) in further elaborate on the ecological significance of urban voids in their work regarding vacant property in New York City. The authors argue that despite being unused, vacant lots serve an important function in the city's green infrastructure. They examine how vacant property contributes to the city's ecological well-being by providing green space that supports urban wildlife and contributes to the overall quality of life of city residents. This position is in accordance with the overarching ecological discourse in urban planning that focuses on the importance of integrating nature as a part of the city to create a more sustainable and resilient urban environment.

Social and Economic Dimensions

Urban voids also have important social and economic consequences. The distribution of these places within the city reveals the general patterns of inequality and marginality. According to Bowman and Pagano (2004), the socioeconomic aspect of this problem is discussed in the book "Terra Incognita: Vacant Land and Urban Strategies." The authors claim that these spaces are mainly concentrated "in inner-city and other declining low-income neighborhoods", and, therefore, the phenomenon of urban voids tends to strengthen social inequality.

Nevertheless, urban voids can also be beneficial to the community by leading to a community-led regeneration. Davis has written about research stating that urban voids, when redeveloped with the involvement of residents, can serve the purpose of becoming community assets. Some examples of such usages include the development of community gardens, the conduction of pop-up markets, and the organizing of cultural events. As such, urban voids can serve as areas of green space in the form of a garden, a space enabling the community to purchase fresh produce or a space where cultural events take place. Additionally, the organization of the urban voids with the involvement of the residents can contribute to the establishment of the feeling of community ownership and local pride.

Challenges and Opportunities of Urban Voids

Like any other typology, opportunities are available in urban voids, but there are challenges, too. Some of the negative correlates of urban voids include scarcity of public areas, low public involvement, and inadequate design. Consequently, people who live in these planned cities lack proper social interactions and regular participation in social activities (Rathi & Kushwah, 2017). In the same regard, public involvement in the planning process is often restricted to inadequate spaces. This can result in the formation of the unsuitable environment which may not be conducive for use and hence remain barren.

According to Franck & Stevens (2007), an important concept is that of "loose space," meaning that the urban void can be temporarily utilized even if existing planning laws make it difficult to do so. Temporary urbanism creates possibilities for free and experimental use of open spaces, land and other abandoned or underutilized areas. This approach has been backed up by prior studies in Europe which show that temporary measures can mobilize people, change the outlook of property owners and may affect subsequent agendas for planning reforms. (Groth & Corijn, 2005)

Voids as Problems and Assets

One of the most apparent ideas that can be identified in the literature is the fact that voids are both a challenge and an opportunity in the context of urban spaces. On one hand, these spaces are constructed as negative par excellence, representing disinvestment, disfigurement, and decay. They can be regarded as obstructions to urban progress and can lead to the loss of interest in the area and its abandonment. On the other hand, urban voids are full of potential waiting to be capitalized and developed. They can be converted into public and ecosystem services for the Indigenous population's welfare and to improve the urban setting.

It is, therefore, crucial to change one's way of looking at the gaps in the urban fabric, the need to abandon seeing such spaces as relevant only as negative elements that have to be rectified or filled. This entails awareness of the causes of the formation of urban voids and ideas on how to use them. It is imperative to measure these spaces accurately and understand their properties to be able to plan their inclusion into the urban structure efficiently.

Research Gap and Objectives

For all of the acknowledgment of opportunities that urban voids afford, this perspective still lacks a steady definition or systematic monitoring of the phenomenon, especially in cities like Islamabad. While these spaces exist in Pakistan, they are linked to negative interpretations, signifying lost chances for community enhancement and city reformation. In the context of the global city, these 'voids' can take up significant parts of the urban geography, yet their size and significance are often unknown or measured inconsistently. For example, voids in American cities are equal to 12. 5-9% of the total land area depending on the country. In South Asia, they cover 3-5 % of the total land area, while in South America, they cover between 4 % and 5 %. 6% to 44%, proving the necessity of precise definitions and regular monitoring (Bowman & Pagano, 2004; Larangeira, 2003).

These voids are not merely wasted spaces; they are silent yet powerful indicators of the underlying urban dynamics at play, from socio-economic disparities to the effectiveness of urban planning. As Pizzagalli (2013) emphasizes, they are not simply negative spatial entities but constitute significant urban components that are potentially transformative. They are, therefore, dynamic factors whose effects are a result of the growth, decline, or change that takes place in a city, acting as crucial 'urban regulators.' Their presence can either advance or stagnate the growth of a city, making their study not just relevant but imperative for any serious discourse on sustainable urban development.

Objectives of the Study

To Define Urban Voids: Ensure that there is a concise understanding of what constitutes urban voids for measurement purposes, especially in the context of Islamabad.

To Quantify Urban Voids in Islamabad: Analyze and map the distribution and extent of urban voids within the city, identifying their spatial patterns and scope.

To Classify Urban Voids: Develop a classification system based on the origins and characteristics of voids, such as planning, functional, and geographical voids.

To Assess Impacts and Explore Potential Uses for Urban Voids: Investigate the socioeconomic and environmental impacts of urban voids on local communities and propose innovative interventions for repurposing these spaces into valuable community assets.

To Examine the Implications of Urban Voids on Sustainable Land Use Planning: Evaluate how the presence and redevelopment of urban voids affect sustainable land use planning in Islamabad, considering ecological, social, environmental, and economic factors.
Thus, the purpose of this research is to help understand the current state of urban voids in Islamabad and the significant possibilities for sustainable changes that will improve living standards across society while considering the impact on the environment.

MATERIALS AND METHODS

This study uses a descriptive research design, which involves both observational and survey research, to describe and quantify the extent of urban voids in Islamabad, Pakistan. These methods are designed to enable the systematic accomplishment of the study objectives.

Overview of Methodologies

Information on the methodologies associated with each of the research objectives is provided in Table 2.

Literature Review & Expert Discussions for Defining Urban Voids

After completing a critical review of the literature on urban voids and conducting interviews with experts, this study operationalized the concept of urban voids within the political and geographical context of Islamabad. The literature review process involved searching through academic databases and publications in order to collect information and definitions from around the world about what constitutes urban voids. Building from this initial framework, further interviews were held with urban planners in Islamabad to operationalize these definitions at the local level. This approach ensured that the definition of urban voids was grounded in academic rigor while also appropriate for the empirically specific urban condition of Islamabad.

Table 2: Research methodology (author generated).

Objective	Methodology	Description	Tools / Techniques	Outcome
To Define Urban Voids	Literature Review & Expert Discussions	An extensive review of global definitions of urban voids, contextualized to Islamabad's unique urban fabric through discussions with local planners.	Academic databases, publications, expert consultations	A refined, context-specific definition of urban voids in Islamabad.
To Quantify Urban Voids in Islamabad	Figure-Ground Analysis	Mapping and quantification of urban voids using satellite imagery to identify the distribution and extent of these spaces.	Google Earth Pro, GIS tools	Identification and quantification of 282 urban voids.
To Classify Urban Voids	Ground Truthing	Field verification of identified voids to classify them into planning, functional, and geographical voids.	Field surveys, observational tools	Classification of voids based on origin and characteristics.
To Assess Impacts and Explore Potential Uses for Urban Voids	Unstructured Interviews	Interviews with local architects and planners to gather insights on the socio-economic and environmental impacts of voids and potential reuse strategies.	Interview guides, thematic analysis	Insights into impacts and potential repurposing strategies.
To Examine Implications on Sustainable Land Use Planning	Literature Review & Expert Discussions	Evaluation of the implications of urban voids on sustainable land use planning, informed by relevant literature and discussions with city planners.	Academic publications, expert consultations	Analysis of how urban voids affect sustainable urban growth and development in Islamabad.

Figure-Ground Analysis for Identification and Quantification

The first step in our exploration involved a figure-ground analysis using Google Earth Pro, chosen for its ability to provide high-resolution imagery that allowed us to see the city in detail. We focused on 19 sectors of Islamabad, selected for their diversity in terms of land use, population density, and the presence of known voids. Each sector was carefully digitized, with built areas highlighted against the unshaded open spaces. This method provided a clear visual contrast, making it easier to identify potential voids. To ensure accuracy, we cross-referenced our digitized maps with official land use plans from the Capital Development Authority (CDA), adjusting where discrepancies arose.

Ground Truthing for Classification

This process was accompanied by a series of windshield surveys and field trips to what was considered the ground truth. In total, 411 of the open areas were discovered to be functionally optimal; thus, 282 were potential voids to explore. This process enabled the categorization of voids into planning, functional, and geographical voids.

Unstructured Interviews for Identifying Impacts and Potential Uses

To explore the implications of urban voids on sustainable land use planning, unstructured interviews were conducted with 20 local architects and planners. These interviews provided valuable insights into the challenges and opportunities associated with urban voids, particularly in the context of Islamabad.

Literature Review & Expert Discussions for Implications on Sustainable Land Use Planning

The study also examined the implications of urban voids on sustainable land use planning through a focused literature review and further discussions with city planners. The literature provided a theoretical foundation for understanding sustainable land use practices, while the expert discussions offered practical insights specific to Islamabad. This dual approach enabled a comprehensive evaluation of how urban voids impact the city's ecological, social, environmental, and economic sustainability.

Figure-2: Mapping after figure ground analysis (Author Generated).

RESULTS AND DISCUSSION

Defining Urban Voids

Islamabad is uniquely placed and architecturally different from other cities in Pakistan, mainly because it was a planned city constructed by the Greek architect Doxiadis in the 1960s. The city was designed to have a clear pattern of green belts and broad avenues that divided the areas of residence, business, and government. Nonetheless, various researchers have pointed out that there are the aspects of the structured layout that have, over a period of time, given way to what can be called the 'urban voids,' that is, the spaces that are either underutilized, abandoned, or provided with inadequate infrastructure.

Urban voids in Islamabad are abandoned, abandoned or unused spaces that have arisen within the planned city due to different circumstances such as poor physical planning and design, socio-political transformations, and fluctuating city patterns. These voids are different from the voids seen in organically grown cities because Islamabad is not an organically grown city but a planned city.

Planning Inefficiencies

The master plan of Doxiadis for Islamabad contained several green belts and buffers designed to act as lungs for the city. Nevertheless, some of these spaces have remained underutilized or abandoned due to a lack of proper maintenance or further development. For instance, some of the green belts that were intended to be used as public spaces have been allowed to deteriorate or be occupied, thus becoming urban voids.

Socio-political Changes

In the period of its existence, Islamabad has gone through various political and economic transformations, such as growth in the rate of urbanization, migration, and changes in governmental policies. Such transformations have sometimes resulted in some parts being deserted or left in a state of disuse, especially in sectors whose planned development did not expand in tandem with the growth of the city. These are places that are left unattended by the community and the government, and this makes them part of the urban blanks of Islamabad.

Table 3: Remnant void number, area and %age in Islamabad (author generated).

	FUNCTIONALLY OPTIMUM VOIDS	REMNANT (DYSFUNCTIONAL) VOIDS	TOTAL
NUMBER	129	282	411
AREA (SQFT)	25,402,742	155,442,314	180,845,056
%AGE	14.05%	85.95%	100

Figure-3: Picture of functional and dysfunctional spaces.

Evolving Urban Dynamics

Islamabad was populated after its creation and has increased to a considerable number, which poses a challenge to its infrastructure and social places. Places that used to be seen as secondary or less vital are now deemed crucial, but their infrastructures have failed to evolve in pace with the increased level of relevance. This conflict has led to areas of wasted or underused spaces—urban voids—intermingling with the studied geometry of the cities where they are located.

However, it can be stated that the current voids in the city of Islamabad can be marked as both – the outcomes of historical decisions in the scope of urban planning as well as the results of the modern tendencies within urban environments. They are spaces that theoretically are designed for certain activities given the master plan of the city but which are abandoned or underutilized for one reason or another. Therefore, recognizing and establishing these spaces can provide a chance to reinstate them to the entire city formation and transform these deficiencies into assets.

This definition contextualizes the concept of urban voids within Islamabad, distinguishing it from global definitions and focusing on the city's unique characteristics. By doing so, the study can better explore how these voids can be quantified, classified, and repurposed to enhance Islamabad's urban environment.

Quantifying Urban Voids in Islamabad

Recently, Islamabad has undergone extensive rebuilding, with transportation interventions such as signal-free corridors, bridges, and underpasses for high-speed traffic. This transformation has resulted in a city more suited for cars than people, leading to the expansion of unwanted residual spaces known as urban voids, particularly beneath and around these structures. However, these voids also hold significant potential for improving the city, provided their potential is fully explored. With a lack of urban plazas, public life in Islamabad has migrated into these spaces. Figure 2 shows the voids identified through figure-ground analysis.

Only 14% of the identified voids function optimally as public spaces or parks. Their success is attributed to strategic location, proximity to essential amenities such as hospitals and schools, and the presence of necessary facilities like waste receptacles and benches. Table 3 provides a comparative analysis of these details.

The contrast between optimally functioning and dysfunctional spaces is striking, as shown in Figure 3. On the left, a well-utilized public space with play structures encourages community engagement, while on the right, a neglected space illustrates the need for thoughtful intervention and revitalization.

Classifying Urban Voids

Dysfunctionality in these spaces can be attributed to factors such as lack of amenities, poor location, insufficient aesthetic quality, and an overall lack of character, resulting in spaces that fail to contribute positively to the urban environment. This research specifically addresses the remnant urban voids within the

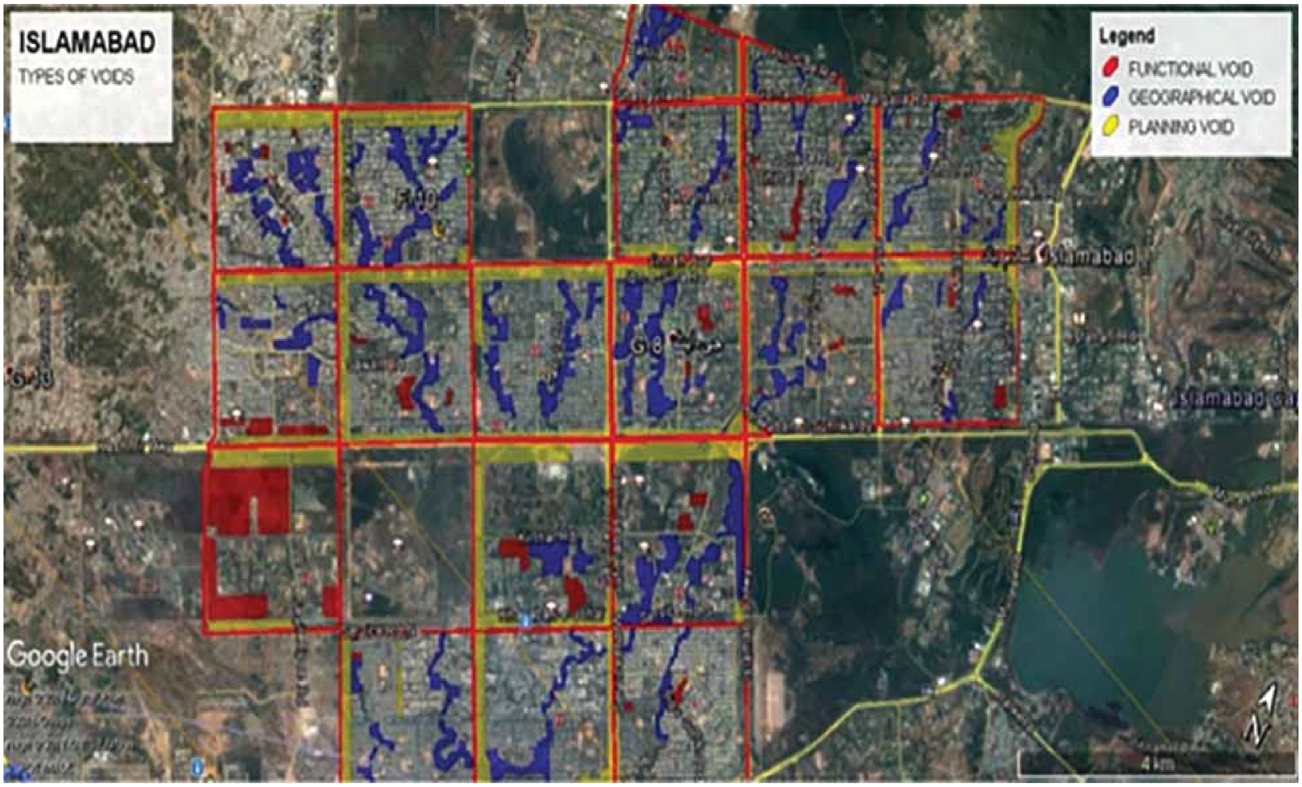


Figure-4: Classification after ground truthing (Author generated).

city, aiming to provide a comprehensive understanding of their current state and potential. Extensive windshield analyses, field excursions, and thorough literature reviews have led to a detailed classification system for these voids, shown in Figure 4. By identifying the key factors contributing to their dysfunctionality, we can propose targeted interventions to transform these neglected spaces into vibrant, functional parts of the urban landscape.

Table 4 illustrates the number of planning, geographical, and functional voids across all sectors of Islamabad. Overall, planning voids outnumber geographical voids, while functional voids are least common. This can be attributed to Doxiadis's plan for the city, which included planning voids between each sector to provide the city with breathing buffers.

Planning voids primarily consist of green belts and buffers between sectors. Illegal car parking on the green belts along the Islamabad highway poses significant issues for the Capital Development Authority (CDA). Influential individuals have made massive encroachments on CDA-owned land, and the civic management has failed to take action against these violators.

The route, which has become a hub of encroachments by the influential, is used by important government and international dignitaries, thereby posing a security threat. According to documents available with Pakistan Today, the Director of Environment had written a letter to the Vigilance Wing of the Enforcement Directorate, stating that the powers of removal of encroachments from government land and matters related to unauthorized

Table 4: Types of urban voids (author generated).

	NUMBER OF VOIDS	AREA OF OF VOIDS	PERCENTAGE OF VOIDS
TOTAL	158971182	282	
PLANNING	76479562	133	48%
GEOGRAPHICAL	60760388	97	38%
FUNCTIONAL	21731232	52	14%

construction on private land have been decided under sections 49B, 49C, 49D, and 49E of the CDA Ordinance, 1960, martial law regulations 63 and 83, as well as a 2005 Cabinet decision of the federal government.

“There are numerous illegal parking areas, such as CDA's land illegally occupied by the renowned shopping mall Centaurus, which turned the land into a parking area—Ufone did the same. Illegal parking areas in sector G-8 are encroached upon by car showroom mafias, and similar situations are seen in sectors G-9, F-7, F-8, and F-10,” claimed an official from the Enforcement Directorate, who requested anonymity.

When contacted, the CDA Director for Public Relations acknowledged the presence of encroachment mafias in the federal capital. He stated that the Enforcement Directorate and CDA had conducted many operations against them, but they kept returning. The Enforcement Directorate demolishes encroachments daily, he said and added that if anyone has encroached on CDA's land, it will also be vacated soon.

Islamabad has about 26 rainwater streams that carry hill torrents. These streams cross residential sectors before finally falling into the Soan and Kurang rivers. Residential sectors dispose of their domestic wastes into the Nalla, which, in low rain seasons, becomes a breeding ground for mosquitoes and emits foul odors.

Figure-5: Major critical zones of Islamabad (Author generated).

The Kurang and Soan rivers pass through Islamabad and the twin city of Rawalpindi via the outskirts. The Kurang River flows from the north to the south side of the city, passing through the eastern outskirts. Meanwhile, the extensive network of Nallah Lai flows through various sectors of Islamabad and parts of Rawalpindi. Saidpur Kas, Tenawali Kas, and Bedarawali Kas are three tributaries of Nallah Lai, primarily starting from Margalla Hill, bringing downhill torrents. These streams join Nallah Lai after passing through the city, which then joins the Soan River after passing through Rawalpindi.

This research identifies major critical voids along the banks of these streams, which are not only contaminated but also prone to flooding. Some densely populated slum developments are located at these sites. The building materials used in these slums—primarily mud, stone, and wooden logs—are not strong enough to withstand natural disasters during heavy rain seasons. During peak monsoon rain seasons, floods cause significant inconvenience to slum dwellers, resulting in injuries, casualties, and other economic losses. Population density can exceed 4,400 people/km² along Nallah Lai. Four major critical zones have been identified and are indicated in Figure 5.

Assessing Impacts and Exploring Potential Uses for Urban Voids

The socioeconomic and environmental impacts of these voids are significant. Most of the identified voids are owned by the public sector, with only 4.07% owned by the private sector (details in Table 5). As this paper primarily focuses on public-owned remnant voids, the emphasis on public ownership is significant because these voids offer greater potential for community-oriented redevelopment projects. Publicly owned spaces can be more easily transformed into parks, community gardens, or other public amenities

Publicly owned spaces can be more easily transformed into parks, community gardens, or other public amenities that serve the needs of the wider community. In contrast, privately owned voids often face legal and bureaucratic hurdles that can complicate or delay redevelopment

Table 5: Ownership status of voids (Author generated).

	PRIVATE	PUBLIC
NUMBER	37	245
AREA	6558912	154225036
%AGE	4.079332596	95.920667

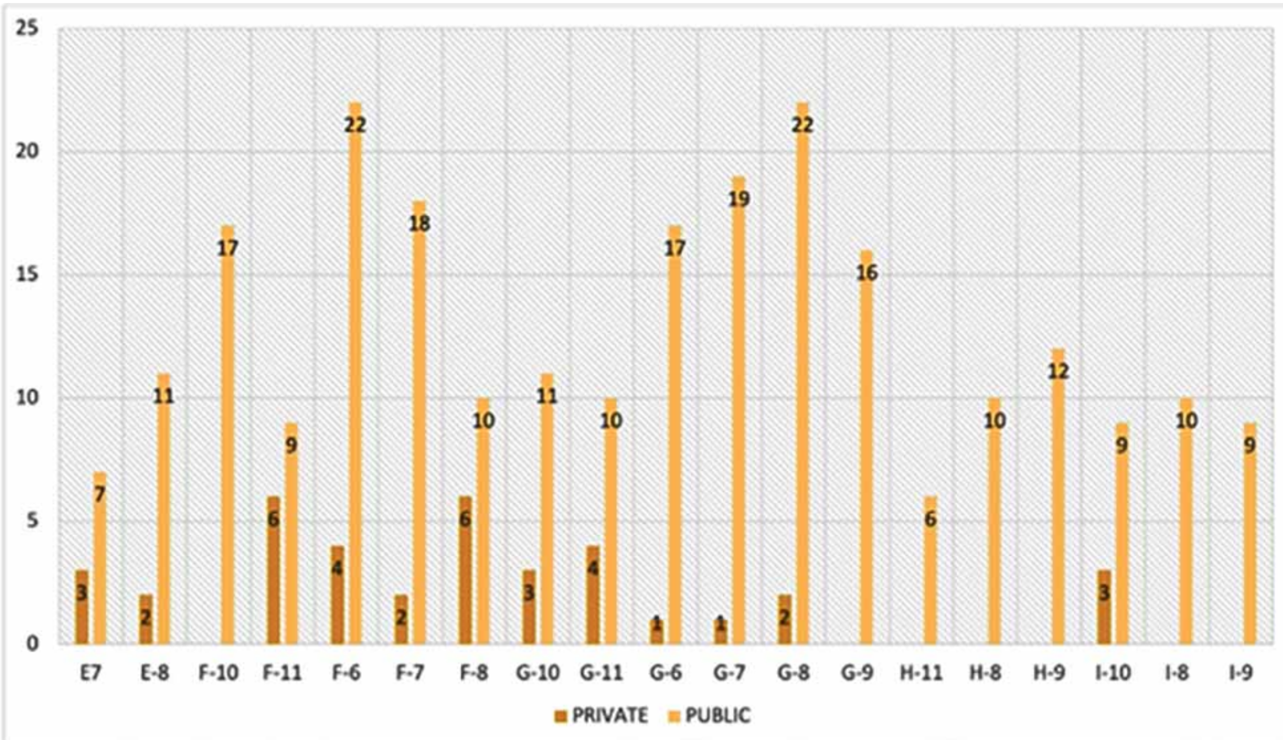


Figure-6: Comparison of number of private and public remanant voids (Author generated).

efforts. By concentrating on public sector voids, this research aims to identify practical solutions for revitalizing these spaces to enhance urban livability and social cohesion.

Figure 6 illustrates that when comparing the total number of public voids with the number of private ones, it is possible to claim that public voids are more numerous. The maximal density of private voids is detected in the F-6 and G-8 sectors; at the same time, the maximal density of public voids is detected in the F-11 and F-8 sectors. This distribution clearly establishes the fact that a huge proportion of voids are publicly owned and hence present vast potential for redevelopment projects that are actually going to advantage the public at large. It is expected that where sectors have more private voids, there might be more difficulties in the process of reusing and remobilizing such spaces when required because some of them are privately owned and may have some legal restrictions.

Figure 7 depicts the private and public void space in all the sectors of Islamabad by analyzing the number of square feet. Specifically, the area of private voids is smaller than the area of public urban voids for private, public, and mixed uses. Sector H-11 contains the highest amount of publicly-owned remnant voids by area, while sector E-7 contains the least amount of publicly-owned urban voids by square footage. On the other hand, the area of remnant voids owned by the private party is maximum in the sector G-11.

This comparison shows the significant number of publicly owned voids that are comparatively much larger than their privately owned counterparts. Such a tremendous difference in area is an indication that many of the publicly owned voids can effectively be transformed into various forms of public utilities whose absence has the potential of significantly diminishing the liveability of the city.

By comparing Islamabad with other cities across the globe in terms of this study, this research realizes that the city possesses a moderately adequate number and size of voids. This means that even though Islamabad has difficulties with urban voids, it has the prospect of redevelopment and regeneration. Based on this, table 6 also shows a comprehensive comparison of the amount of vacant land found in Islamabad with those of equivalent cities around the world.

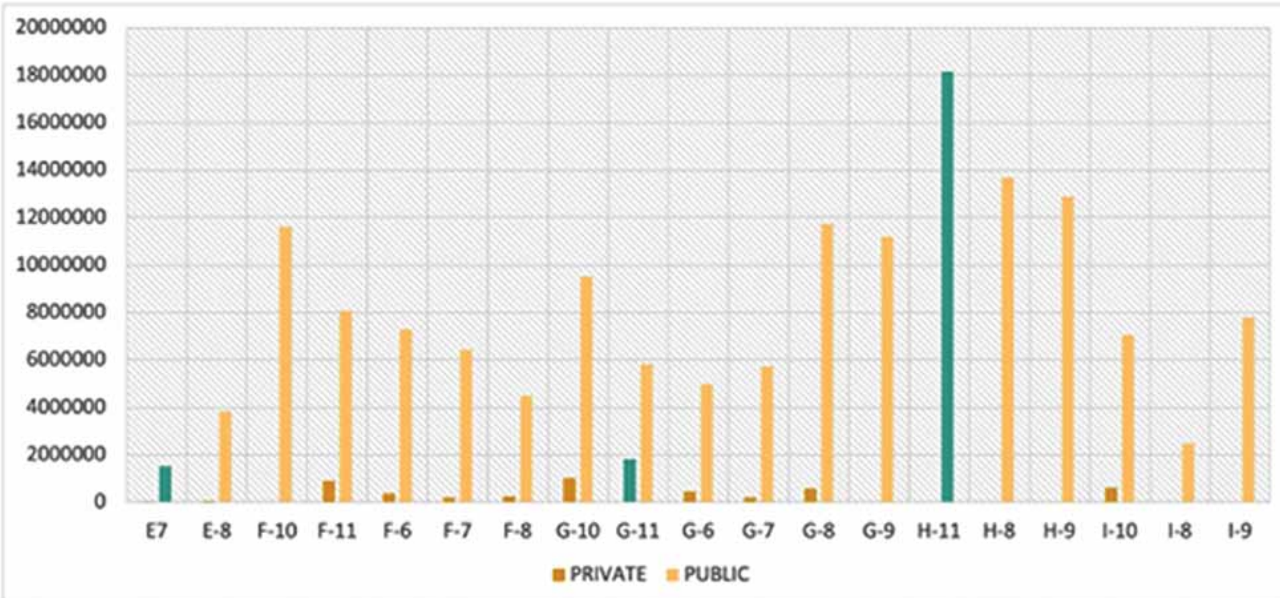


Figure-7: Comparison of number of private and public remanant voids in different sectors of Islamabad (Author generated(.

Table 6: Comparison of amount of vacant land in 15 different cities (Author generated).

CITY	CITY AREA (ACRES)	VACANT LAND (ACRES)	%AGE OF VACANT LAND
Rio De Janerio, Brazil	124727.27	54880.00	44.00%
Phoenix, USA	300469.48	128000.00	42.60%
Guayaquil, Ecuador	81532.11	32123.65	39.40%
Buenos Aires, Argentine	334364.47	106996.63	32.00%
Orlando, USA	62717.77	18000.00	28.70%
Guadalajara, Mexico	37158.65	9884.20	26.60%
Islamabad, Pakistan	15943.84	3691.00	23.15%
Quito, Ecuador	46462.57	10082.38	21.70%
Shimokitazawa & Taishido, Tokyo	NA	NA	20.40%
Mexicali, Mexico	36800.12	7017.78	19.07%
New Dehli, India	366704.4	5484.00	14.95%
Santiago, Chile	123560.54	14048.83	11.37%
Lima	695652.87	52591.36	7.56%
San Salvador , El Salvador	557.98	25.95	4.65%
Baltimore, USA	52631.58	1000.00	1.90%

Implications of Urban Voids on Sustainable Land USA Planning

Notably, urban voids are perceived to be dilapidated areas that lack civil amenities, which are associated with criminal activities and the accumulation of waste. These abandoned areas are a nuisance to public order as they do not have social and economic activities, which affects the dynamics of people's interaction in their neighborhoods. For local architects and planners, such places remain a major concern in the process of rehabilitating civil life. However, if properly managed, such voids can be worked into opportunities where they are developed into valuable assets to the community. When integrated and well redeveloped, cities with voids prove immensely valuable to society, ecosystems, and the environment, helping people enjoy the green areas they once shunned.

For the restoration of this equilibrium, society is forced to comprehend the dynamics that respond to social demands within the process of Urbanization. Studying the trends of worldwide urbanization that may respond to such issues as climate change and other environmental pressures demonstrates that such spaces need to have a dynamic redevelopment strategy.

At present, over half the population of the developed world lives in cities, a mark that could rise past 65% by 2050; therefore, there is a particular focus on the exploration of interactive links between society and nature that we see manifesting themselves in urban growth plans and designs. Islamabad's accompanying environment is a perfect blend of urban environment and natural beauty and thus has a tremendous potential for the enhancement of sustainability. However, some opinions stress that overdeveloping the city, the ecological benefits are neglected, and the process of development is ruining the environment. Therefore, it is essential to undertake actions that will correct the imbalance created by the urban expansion processes to

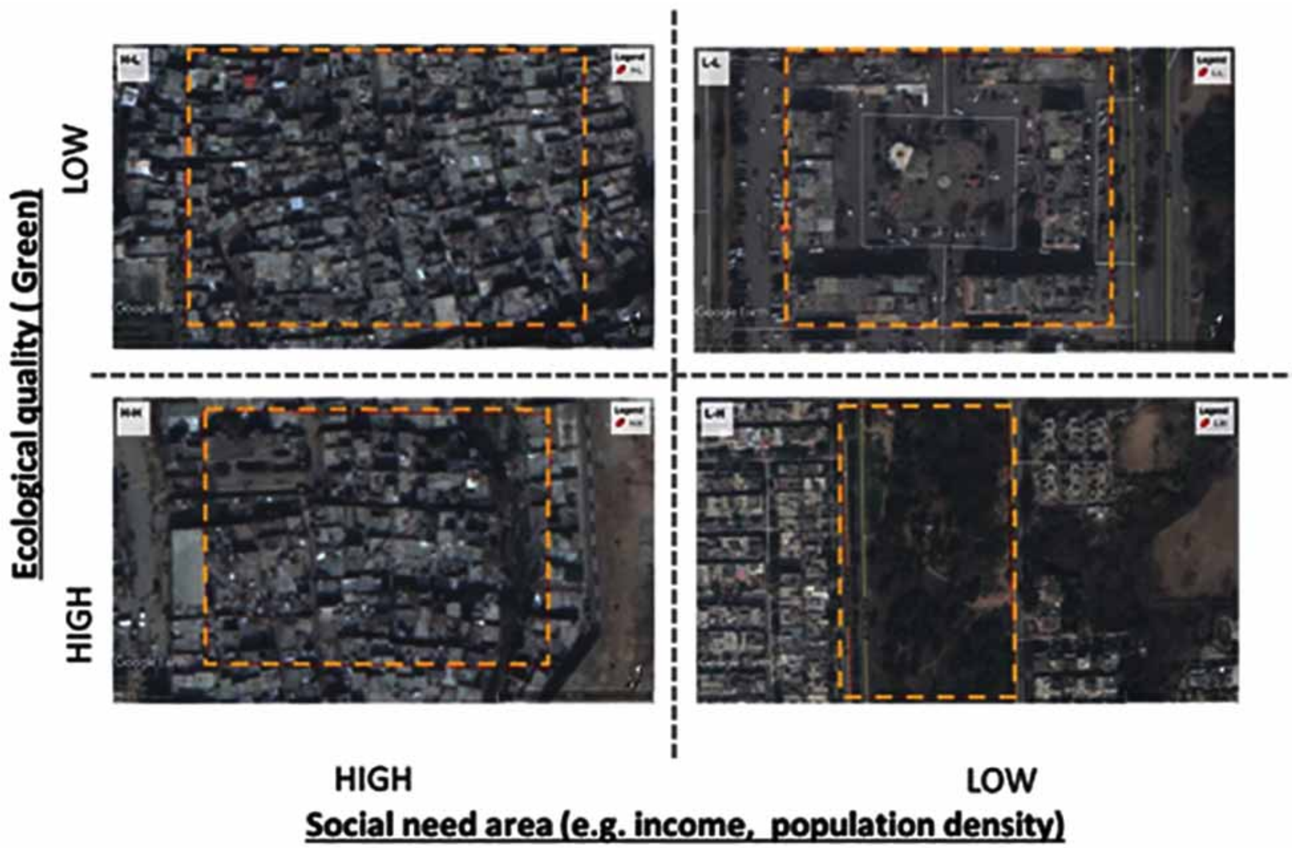


Figure-8: Satellite imagery of urban voids in Islamabad (Author generated).

rehabilitate the ecosystem of Islamabad and, thereby, increase the quality of urban living standards and the vitality of the city.

Hence, it has become imperative to grab this chance to bring change into the open voids and convert them into green homes for the public. The benefits likely to arise from such initiatives for Islamabad residents include:

- Ecological Benefits: The alteration of voids in urban contexts can play a role in enhancing ecological sustainability. These areas can be effectively used as urban stormwater management techniques and as water conservation features. They assist in the moderation of temperatures, particularly the air, and the reduction of wind force, thus improving the climate in urban areas. At the same time, urban voids can perform the function of air cleaning, assimilating emissions and enriching the air and the atmosphere with oxygen. They also participate in carbon uptake and thereby come in handy in controlling greenhouse gas emissions. From this, such zones prevent water-related risks in the urban environment by offering flood control. Besides, they can be economically transformed into biological micro-habitats for diverse plant species and their pollinators. Greenways can be built to connect and isolate the natural areas of urbanization, which, in turn, increase their ecological stream or health.

Figure-9: Ladies park G10/2.

• Social Benefits: The process of transforming voids in urban areas has several social impacts because it allows people to socialize and support their fellows. Such spaces can be converted into recreational ones, hence giving residents an opportunity to engage in physical activity alongside relaxation. Green spaces may also be created through the provision of community gardening so as to enhance local food production as well as social interactions. In the case of urban voids, they are capable of providing social interaction as well as the space for facilitating communal activities. They can also be employed in short-term art pieces and thus can be accepted due to their ability to enhance the cultural feeling of the city. Also, the process of bringing new built forms to parts of the cities that have become avoidable can help in the reduction of crime as such areas may otherwise be occupied with unlawful uses. Some of the benefits that can be of help include the reduction of noise since green space can help moderate the noise levels in urban areas, making the neighborhoods quiet.

• Environmental Benefits: There are numerous advantages not just to the area but also to the environment whenever urban voids are redeveloped. People and communities can effectively work towards the improvement, decor and gratification of their neighborhood and surroundings. These spaces can develop such a great context and can develop a community of people related to space. These activities provide chances for delivering environmental education whereby community members get to familiarize themselves with environmental and ecological concepts. Furthermore, remade urban voids can positively impact the well-being of residents as they give them the opportunity to relax and enjoy beautiful and quiet places.

• Economic Benefits: The opportunities for getting economic benefits from the change of urban voids are rather large. The value of properties located in these newly redeveloped areas is likely to rise, thus enhancing property owners' earnings and supporting the economy. Public parks in poor communities can ensure equal availability of resources and quality facilities for all citizens to enjoy. Moreover, the natural cooling that comes with green spaces can also result in energy conservation on residential and commercial buildings.

Regarding these aspects, the restoration of urban voids can greatly improve sustainable urban development, as well as the environmental and socio-cultural context of Islamabad. Analyzing four precedents from the United States of America, some cities have begun to understand the effective and efficient use of every inch of urban land. After the environmentally friendly redevelopment of urban voids in Philadelphia, the crime rate saw a substantial drop. The redevelopment measures in Detroit helped transform these voids into urban ranches. The open spaces in Brooklyn (New York) were converted into gardens, meeting growing food requirements and turning them into social and communal places for the residents. Baltimore (Maryland) is an excellent example of a well-thought-out redevelopment of open spaces with a strong emphasis on biodiversity (Dhamal, 2017).

The objective of this research paper is to map urban voids in the residential sectors of Islamabad and to gain a better understanding of their implications for the sustainable development of the city. Identifying and classifying these ignored urban voids will stimulate debate in planning and development quarters, leading to improved biodiversity, ecosystem balance, and the restoration of social justice.

Although Islamabad's urban voids are relatively green, with trees, wild shrubs, herbaceous plants, and pests, there are vast open redundant spaces where low-income dwellers have mushroomed. This trend of mushroom growth in open voids poses a significant threat to the green infrastructure and ecological balance, besides increasing criminal activity.

We have mapped around 450 open spaces in Islamabad. The mapped redundant spaces present another challenge: they are either very small (less than 10,000 square feet) or earmarked for potential future use. This is a challenge in itself. Therefore, we must also consider non-conventional approaches to develop urban green infrastructure on these voids. Some of these redundant spaces may be suitable for nature conservation, while other oddly shaped voids may be turned into small parks for public interaction. The open corridors adjacent to transportation networks, where other types of development are unlikely, can be developed as public promenades for pedestrian use.

Open voids are located both in densely populated and low-density sectors of Islamabad. Figure 8 exemplifies different types of land use seen in various parts of the city. Densely populated areas are generally less green and lower in ecological quality, while sparsely populated green areas represent the other end of the spectrum.

In this paper, we aim to assess the possibilities of restoring ecological balance in these open voids to further enhance biodiversity and public use of the redundant spaces, especially in sparsely populated areas. Ladies Park (G-10/2), shown in Figure 9, is part of a densely populated residential area and is an ideal candidate for redevelopment. In contrast, the open space in the top-left quadrant of the image above is a perfect example of transforming ecological quality. This green space is located next to a low-income, densely populated locality, sitting on the edge of a Nala and appearing almost disconnected from the urban fabric.

Proper development of these areas is central to the sustainable development of the ecosystem and maintaining biodiversity. While looking at the prospective use of urban voids from a spatial perspective, we must also consider the temporal use of these voids. In this context, a vacant lot earmarked for future planned development can be used in the short run for green infrastructure, meeting the public and ecological needs of the city in the intervening period.
It is high time city planners started conceiving Islamabad's development differently. By focusing on initializing open urban spaces to meet the ecological, social, economic, and cultural needs of the city, we can transform ignored landscapes into communal places, making them eco-friendly and resilient. This approach will better equip the city to address the needs of stressed urban societies.
Involving communities in these initiatives will add tremendous value to the sustainability and long-term efficiency of these measures. This way, we will be transforming our urban voids into greener infrastructure, enhancing the resilience of Islamabad's social and ecological fabric. A lot of effort is required to detail the best use of these urban voids. City planners should seek help from all stakeholders, including ecologists and social scientists, in transforming these spaces. These voids have been ignored for too long, and if Islamabad does not invest in revamping urban voids, the full social and ecological benefits of the city will never be realized. The character of the city depends on the best land use that can create green spaces for recreation, increased public interaction, pollution-free environments, and biodiversity habitats, contributing to the long-term health of the overall ecosystem.

CONCLUSIONS

Urban voids can be seen as absences but also as countless possibilities, encounters, and spaces of great expectations. With careful consideration towards minimizing the cons and maximizing the benefits, the temporary use model can offer a favorable substitution for conventionally followed methodologies for the efficient and effective redevelopment of urban voids. Cities all over the world are changing at a very fast pace, facilitating a variety of agendas, procedures, interests, and values, which often conflict with each other. Cities must be deemed as perpetually evolving entities (Bishop & Williams, 2012).

There is a general trend to control and limit the open-endedness and inherent uncertainty of urban transformations and improvements in professional fields, such as spatial planning and design. This bureaucratic top-down control approach has resulted in monotonous developments with little or no place for difference or identity. It is observed that the most impactful urbanization processes have occurred outside of and often in opposition to structured design and planning endeavors. Owing to the rapidly changing nature of such processes, it is time for planning bodies to reconsider the decision-making process regarding urban development. This paralytic condition can be attributed to post-response analysis and poor resource allocation. The planning process of a city is only considered efficient if it can permit several corrections and rectifications. It is a false hypothesis to begin planning only after all possible variables are under control.

Pakistan is a country where long-term social and economic benefits are hard to guarantee due to its turbulent political history. Therefore, development projects requiring significant capital investment in terms of time, political will, social interest, and fiscal logistics are inappropriate in the context of Pakistan. In such fluid and uncertain conditions, the development of an urbanization model that is more reflexive and responsive to current user demands is therefore identified. A temporary-use model is an effective tool for ensuring that the urban transformational approach is more realistic, rational, and incremental, moving in harmony with our institutional trends and processes of master planning inflexible mega projects.

The temporary use model for the redevelopment of urban voids may also bring the perks of a rich and diverse area highly capable of accommodating tests regarding the effects of various uses of the redundant space. It may also offer an understanding of the effects of new interventions. Alongside aiding in producing empirical data, this model permits quick rectification of approaches if they fail to produce the desired results or cause negative aftermaths.

Additionally, there is an emphasis on overcoming traditional centralized and sectionalized planning and implementation processes through the temporary use model. It is safe to assume that the proliferation of urban voids is a result of the compartmentalized planning approach.

To facilitate the temporary use model, an entire variety of systems, processes, and suitable conditions need to be established beforehand. Therefore, it would be short-sighted to view urban voids as useless or merely a problem while completely ignoring their potential as substantial contributors to effective and efficient urban systems functioning. Urban voids have untapped potential for functioning as systems that help accommodate public realms, which are otherwise expensive and scarce commodities in the context of Islamabad.

REFERENCES

Aleha, A., Zahra, S. M., Qureshi, S., Marri, S. A., Siddique, S., & Hussain, S. S. (2023). Urban void as an urban catalyst bridging the gap between the community. *Frontiers in Built Environment*

Aporee (2011) *online*. Available at: http://poree.org/parole/work/index.php?char=u (Accessed: 6 January 2011).

Bishop, P. and Williams, L., (2012). *The temporary city* (p. 19). London: Routledge.

Bowman, A.O. and Pagano, M.A. (2004) *Terra incognita*: Vacant land and urban strategies. Washington, D.C.: Georgetown University Press.

Bowman, A. O'M., & Pagano, M. A. (2000). *Vacant land in cities*: An urban resource. Brookings Institution, Center on Urban and Metropolitan Policy.

Clément, G. (2004). *Manifeste du tiers paysage*. Éditions Sujet Objet.

Coleman, A. (1982) 'Dead space in the dying inner city', *International Journal of Environmental Studies*, 19, pp. 103-107.

De Araujo Larangeira, A., 2003. Vacant Land in Latin America: Challenges and Opportunities. *Lincoln Institute of Land Policy*, Cambridge, p.39.

De Girolamo, F. (2013) 'Time & regeneration: Temporary reuse in lost spaces', *Planum: The Journal of Urbanism*, n.27.

Dhamal, N.M. (2017) *Reimagining lost spaces in a city: case of Pimpri*, Pune. Doctoral dissertation. SPA Bhopal.

Douglas, O., Lennon, M. and Scott, M., 2017. Green space benefits for health and well-being: A life-course approach for urban planning, design and management. *Cities*, 66, pp.53-62.

Dovey, K. and Pafka, E. (2016) *Urban design thinking: A conceptual toolkit*. London: Bloomsbury Publishing.

Elmeligy, E., Al Arnouty, S.M. and Ebrahim, S. (2024) 'Temporary Architecture: A study of revitalizing Alexandria's urban voids', الدورية العلمية لكلية الفنون الجميلة , pp. 73-86.

Express Tribune Report (2016) 'Drug addicts, beggars and makeshift shops have overtaken the empty spaces', *Express Tribune*, 14 February. By Oonib Azam.

Franck, K.A. and Stevens, Q. (2007) L*oose space: Possibility and diversity in urban life*. London: Routledge.

Groth, J. and Corijn, E. (2005) 'Reclaiming urbanity: Indeterminate spaces, informal actors and urban agenda setting', *Urban Studies*, 42(3), pp. 503-526.

Hajer, M. A., & Reijndorp, A. (2001). *In search of new public domain*: Analysis and strategy. NAi Uitgevers.

Hashem, O. M., Wahba, S. M., & Nasr-Eldin, T. I. (2022). Urban voids: Identifying and optimizing urban voids potential as a revitalization source in enhancing developing countries' city income. *Journal of Engineering and Applied Science* (Cairo), 69(1)

Hwang, S.W. and Lee, S.J. (2020) 'Unused, underused, and misused: An examination of theories on urban void spaces', *Urban Research & Practice*, 13(5), pp. 540-556.

Jakle, J.A. and Wilson, D. (1992) *Derelict landscapes: The wasting of America's built environment*. Savage, MD: Rowman & Littlefield.

Kremer, P., Hamstead, Z.A. and McPhearson, T. (2013) 'A social–ecological assessment of vacant lots in New York City', *Landscape and Urban Planning*, 120, pp. 218-233.

Kushwah, N. and Rathi, K., 2017. Urban voids–reclaiming urban space. *International Journal of Advance Research, Ideas and Innovations in Technology*, 3(1), pp.196-203.

La Varra, G. (2003). Post-it city: The other European public spaces. In S. Boeri (Ed.), *Multiplicity: USE-Uncertain States of Europe* (pp. 92-97). Skira

Lopez-Pineiro, S., 2020. A glossary of urban voids. In *A Glossary of Urban Voids*. JOVIS Verlag GmbH.

Loukaitou-Sideris, A. (1996). Cracks in the city: Addressing the constraints and potentials of urban design. *Journal of Urban Design*, 1(1), 91-103.

Lynch, K. (1960) *The image of the city*. Cambridge, MA: MIT Press.

Mathey, J. and Rink, D., 2010. Urban wastelands–a chance for biodiversity in cities? Ecological aspects, social perceptions and acceptance of wilderness by residents. *Urban biodiversity and design*, 7(1), pp.406-424.

Nielsen, T. (2002). The return of the excessive: Superfluous landscapes. *Space and Culture*, 5(1), 53-62.

Northam, R.M. (1971) 'Vacant urban land in the American city', *Land Economics*, 47(4), pp. 345-355.

Oswalt, P., Overmeyer, K. and Misselwitz, P. (2006) 'Patterns of the unplanned', in Frank, K. and Stevens, Q. (eds) *Loose space*. London: Routledge, p. 275.

Pizzagalli, S. (2013). *Spaces, poetics and voids*. Architectura & Natura Press.

Quaiyoom, O. (1997) 'Islamabad – the first planned city', *Book of Abstracts*, p. 15.

Rathi, K., & Kushwah, N. (2017). Urban voids reclaiming urban space. *International Journal of Advance Research, Ideas and Innovations in Technology*, 3(1), 196-203.

Solà-Morales, I. de. (1995). Terrain vague. In C. Davidson (Ed.), *Anyplace* (pp. 118 123). MIT Press.

Sommer, R. (1974). *Tight spaces: Hard architecture and how to humanize it*. Prentice-Hall

Schoonderbeek, M. ed., 2013. *Spaces, poetics and voids*. Architecture & Natura Press.

Secchi, B., 1993. For a town-planning of open spaces. In *The Design of Open Spaces* (pp. 597-598).

Tapner, V., 1977. Islamabad: City Without a Heart. *Building Design*.

Trancik, R., 1991. *Finding lost space: theories of urban design*. John Wiley & Sons.

Worpole, K., & Knox, K. (2007). *The social value of public spaces*. York, UK: Joseph Rowntree Foundation.

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING
Volume 35 Issue 2
ISSN (P) 1728-7715 - ISSN (E) 2519-5050
Journal DOI: www.doi.org/10.53700/jrap_neduet
Issue DOI: www.doi.org/10.53700/jrap3522025

IMPACTS OF ABANDONED RAILWAY LANDSCAPES ON SOCIAL WELLBEING AT RATMALANA, COLOMBO, SRI LANKA

Kaha Kachchi P. S. Amandi, Anishka A. Hettiarachchi***

Article DOI:
www.doi.org/10.53700/jrap3522025_5

Article Citation:
Amandi, K.. P. S. and Hettiarachchi A. A., 2025, Impacts of Abandoned Railway Landscapes on Social Wellbeing at Ratmalana, Colombo, Sri-Lanka, *Journal of Research in Architecture and Planning,* 35(2). 74-90.

* Graduated Landscape Architect, Univesity of Moratuwa, Katubedda, Sri-Lanka.
shashimamandi997@gmail.com
ORCID: 0009-0006-3871-4094
** Ph D., Professor, Univesity of Moratuwa, Katubedda, Sri-Lanka.
anishkah@uom.lk

ABSTRACT

The study examined the impacts of abandoned railway landscapes on the social well-being (SWB) of residential communities in Ratmalana, Colombo, which was shaped by neoliberal urban forces. The research adopted a theoretical framework integrating Urban Decay and Social Capital theories, complemented by the Spiral of Decline and Broken Windows theories. Six key available abandoned landscape (AAL) impacts were conceptualized as independent variables. At the same time, the Personal Well-Being Index-Adult (PWI-A) was employed to assess seven domains of subjective well-being as dependent variables. Through a mixed-methods approach, data were collected using spatial observations, documentation, and surveys with fifty residents, based on an author-designed questionnaire and the PWI-A scale. Findings revealed that visual blight (2.12) was the most salient source of dissatisfaction associated with AALs, while the future security dimension recorded the lowest overall score in SWB (1.86). The community was classified as "No Well-being" (NW) due to the overall SWB being measured at 36% on the PWI-A scale. It was concluded that adaptive reuse, safety enhancement, inclusive participation, and balanced investment could create well-being-centered, equitable, and community-driven approaches to urban policy. Such approaches were proposed to counter urban decay while revitalizing neglected areas, strengthening social capital, and creating sustainable and socially cohesive urban landscapes.

Keywords: Abandoned landscapes, social well-being, residential community, neoliberal, urbanization, subjective well-being.

INTRODUCTION

Overview of Neoliberalism and impact on worldwide urban societies

The structure and function of urban societies were influenced by neoliberalism, which was characterized by deregulation and privatization (Harvey, 2005; Weaver, 2016). According to Weaver (2016), it placed a high priority on market-based reforms that encouraged government involvement in the delivery of public services while preserving private property. This ideology typically prioritized elite-driven developments and speculative urbanism in urban environments over equitable and inclusive growth (Watson, 2013).

Planning systems in many cities prioritized economic growth rather than addressing the everyday needs of low-income communities. This left these groups increasingly marginalized (Moser, 2015). Across several African contexts, neoliberal urban policies were found to have intensified challenges such as informal development, displacement, and the erosion of local governance structures (Gibson, Legacy, and Rogers, 2023). Gibson et al. (2023) further describe how forms of “state capitalism” and “de jure collusion” reinforced powerful dominance, which often limited genuine public participation in planning. In this sense, neoliberalism reshaped urban governance toward economic accumulation at the expense of public welfare and spatial justice.

Urban transformation in Colombo under Neoliberal influence.

The focus in Colombo shifted due to neoliberal pressures. The city moved from inclusive growth to a development model dominated by market-oriented aspects (Harvey, 2005). Attracting global investment and promoting economic growth became priorities over social justice and the SWB of marginalized communities (Harvey, 2005). As a result, speculative real estate endeavors, massive infrastructure projects, and luxury developments reshaped the social and physical fabric of cities (Abeyasekera et al., 2021; Amarasuriya and Spencer, 2015). Initiatives to build a "world-class city" led to the relocation of working-class populations and the marginalization of working-class districts (Perera, 2015). Public funds were diverted to programs that benefited the elite, while socially integrated metropolitan areas were often overlooked, marginalized, and neglected. Under the pretext of urban modernization and beautification, the Urban Regeneration Project (URP) forced thousands of residents from central Colombo to relocate to suburban high-rises (Perera, 2015).

Need for the Study

This research examined how neoliberal urban policies, driven by market-oriented development, contributed to the creation and persistence of AALs in the city. It further explored how these AALs negatively affected the SWB of surrounding residential communities by disturbing social networks, lowering the quality of life (QOL), and intensifying marginalization.

Research Gap

Existing research had explored the effects of AALs in developed countries and some parts of the Global South (Corsaro, 2015). However, there was a significant gap concerning their socio-spatial and well-being impacts in Sri Lanka. Previous literature primarily focused on displacement, housing policy, and urban regeneration. There was minimal attention to how neoliberal planning contributed to long-term urban neglect and abandonment. The lack of SWB-based empirical data limited understanding of how these policy frameworks affected daily life and community well-being. By using a SWB-focused empirical approach, this study directly investigated the socio-spatial consequences of abandonment in Colombo. It linked Social Capital and Urban Decay theories to observable QOL impacts. This approach filled a critical knowledge gap and provided evidence to inform urban planning and policy interventions in rapidly changing contexts.

Research Objectives

The research objectives (RO) were formulated to examine the processes by which neoliberal urban policies contributed to the emergence of AALs and to assess their effects on SWB.

1: To define AALs and how neoliberal forces contributed to the abandonment of cities, using theoretical frameworks to guide operationalization

2: To examine the impacts of AALs on the SWB of nearby residents, focusing on specific domains and highlighting conflicts between economic priorities and the social health of residents.

3: To evaluate the degree of AAL impacts and their impact on QOL, using PWI-A scores and field observations to demonstrate how neoliberal urban policies influenced local identity and community cohesion.

4: To develop a theoretical framework to illustrate the social impacts of AALs and to propose practical recommendations to protect and enhance local SWB against the pressures of neoliberal urban pressure.

LITERATURE REVIEW

Neoliberal Urbanism and the Increasing Abandonment of Landscapes

According to Brenner and Theodore (2002), the neo-liberalization process contributed to the marginalization and abandonment of metropolitan areas considered unprofitable by economic standards. Consequently, public services and infrastructure were discontinued. Similarly, public investment shifted to growth-oriented and privatized urban rehabilitation projects. Peck and Tickell (2002) highlighted how neoliberal urban policies led to spatial inequality and the deliberate abandonment.

The neoliberal economic agenda, which prioritized market-driven development over the SWB of the general population, was directly responsible for the abandonment of landscapes. As urban centers expanded due to industry and real estate speculation, prevalent traits of neoliberal cities often resulted in neglect (Handy et al., 2006). Neoliberalism was identified as a significant factor in the increased poverty of the Global South, as well as in the perpetuation of inequality, the privatization of public resources, and the greater financial capital power (Boden, 2011). Abandoned landscapes emerged as a byproduct of market-centric priorities, reflecting systemic neglect of the public good in favor of powerful interests (Harvey, 2005; Boden, 2011).

Characteristics of Abandoned Urban Landscapes

Social connection and shared group identity were recognized as protective factors against depression and psychological distress (Cruwys et al., 2014). These were typically areas with limited economic return potential, driven by real estate speculation and industrial rezoning (Handy et al.,2006). Such neglected spaces contributed to heightened community tensions, increased depression, and pervasive fear, as residents contended with visual blight and deteriorating infrastructure that eroded their sense of safety and health (Korpela et al., 2008; Lorenc et al., 2012).

Neoliberalism, driving the growing privatization of public places, is leading to landscapes with less economic value being abandoned. As a result, cityscapes become physically and socially fragmented (Lambin et al., 2003). This demonstrated a failure to incorporate local cultural identities into the comprehensive planning process (Harvey, 2005). Spaces intended for public use were either ignored or transformed into profit-driven ventures. This abandonment reflected the decline of the public good in design, where privatization was prioritized over social needs, degrading the public domain in favor of elite interests (Harvey, 2005). Consequently, vulnerable groups were relocated or excluded, resulting in fragmented cityscapes where accessibility, inclusivity, and social equity were compromised.

SWB in the Context of AALs

SWB was defined as an assessment of how individuals perceived their social world and their role within it, encompassing feelings of belonging, acceptance, contribution, coherence, and a sense of belief in societal growth (Keyes, 1998). According to Sousa Matos (2014) and Krupat (1985), the loneliness and desolation of AALs generated depressive, sentimental, and fearful feelings, which in effect adversely affected the mental health of immediate residential communities. In addition to degrading the natural environment, these AALs erode the interpersonal connections among individuals in society and the trust that is essential for community resilience. According to Keyes (1998), social networks, societal institutions, and a sense of belonging are all intrinsically connected to subjective well-being. These are all endangered in situations where abandonment is prevalent.

Public spaces, originally intended to encourage social cohesion and community engagement, were often overlooked in favor of projects that served corporate interests and international competitive imperatives (Armstrong, 2000; Leyden, 2003). The gap between community needs and urban development goals exacerbated social inequality, while the privatization of public services and decreased government involvement contributed to neglect (Müller, 2013; Piketty, 2015). These policy frameworks, by prioritizing individual achievement over collective welfare, intensified loneliness and social exclusion (Adams et al., 2019).

Abandoned areas continued to weaken community cohesion and sense of belonging, reducing mental health outcomes (Holt-Lunstad et al., 2015). Increased stress, anxiety, and depression among residents of South Asian cities were linked to the interaction of neoliberal policies with urban deterioration (Sennett, 1998). Therefore, the development of social trust and community involvement was identified as crucial to improving SWB. Research indicated that reclaiming abandoned urban spaces enhanced social interaction and significantly improved mental well-being (Cruwys et al., 2014).

Neoliberal urban planning and its social consequences in Colombo

The issues of neoliberal urbanization compelled Colombo to adopt sustainable and socially conscious architectural forms that prioritized social welfare and regional culture. Neoliberal policies weakened community cohesion and increased social inequality by transforming urban landscapes, displacing underprivileged populations, and abandoning public places (Abeyasekera et al., 2019).

Despite their stated goals of modernization and economic progress, state-driven urban regeneration initiatives frequently resulted in the displacement of low-income residents into high-rise flats, disrupting long-standing social networks. It lowers the QOL for the local population (Abeyasekera et al., 2019).

Successful strategies for restoring neglected urban areas and promoting social inclusion were developed in response to these identified problems. These strategies included community-oriented projects like urban gardening, the adaptive reuse of abandoned buildings and structures, and the incorporation of green infrastructure (Bullock, Pywell, and Walker, 2007; Wakefield et al., 2007). Adaptive reuse of Colombo was proposed to transform deteriorated buildings into functional public areas or reasonably priced homes while preserving the cultural legacy of the city and building a sense of belonging in the process.

Planners were encouraged to integrate green infrastructure, such as green spaces, urban parks, and green corridors. It was a priority in urban planning to improve microclimatic conditions, reduce environmental degradation, and enhance SWB. Furthermore, community gardening initiatives were shown to empower residents by promoting social interaction, enhancing neighborhood ties, and enhancing mental health outcomes (Wakefield et al., 2007). Abeyasekera et al. (2019) emphasized the importance of incorporating sustainable and viable design principles into urban planning to combat social disintegration and gentrification resulting from neoliberal urban policies. Colombo was envisioned to become a more resilient, dynamic, and inclusive urban environment that counters the polarizing impacts of neoliberalism and enhances the welfare of all its citizens by emphasizing ecological restoration and community involvement in spatial planning.

THEORETICAL FRAMEWORK

A Structural Perspective of Urban Decay and Neoliberalism

Once thriving urban areas were abandoned and degraded as a result of companies and industries relocating to more financially rewarding locations, which exacerbated social inequality and marginalization (Acioly & Acioly, 1999). This decline was both social and physical, as evidenced by theories such as the Spirals of Decline Theory (Prak & Priemus, 1986) and the Broken Windows Theory (Wilson and Kelling et al., 1982), which demonstrated how visible indicators of neglect encouraged criminal behavior and further isolated previously marginalized communities. Urban regeneration initiatives faced increased challenges due to conflicts between public and private interests arising from the degradation of the urban environment and social fabric.

These practices were representative of the broader consequences of neoliberalism on Urban Decay, which undermined social justice and subjective well-being by prioritizing market-driven development over the inclusive needs of communities (Skogan, 2015; Morrison, 2013). Insufficient urban management and the withdrawal of public investment further exacerbated social breakdown and physical deterioration, leading to overcrowding, unauthorized housing, and an increase in crime in inner-city regions (Prak & Priemus, 1986). For effective intervention, integrated public policies were required to combine social and economic regeneration with physical renewal, coordinated across sectors and supported financially by public-private partnerships (Acioly & Acioly, 1999). Institutional frameworks were needed to empower communities and local authorities to implement technically feasible and sustainable alternatives, thereby promoting equitable urban growth.

Social Capital Theory and Community Resilience

The Social Capital theory posited that addressing urban problems in impoverished areas required strong community networks, trust, and social cohesion (Leyden, 2003). Strong social relationships were recognized as essential for sustainable development. Because they enabled communities to mitigate the detrimental effects of urban deterioration and foster grassroots regeneration, as claimed by Lin (1999) and Flora (1995). The concept of localness, which emphasized the ability to maintain individual identity and autonomy in the face of neoliberal influences, aligned with this theoretical framework. Social cohesion was identified as essential for preserving a sense of place and community identity within the framework of neoliberalism. Substantial social capital enabled communities to resist gentrification, preserve their cultural heritage, and challenge laws that prioritize profit over social values (Falk and Harrison, 1998). To comprehend and facilitate opposition to neoliberal urban policies, social capital, community resilience, and the strength of social networks were identified as key factors (Lin, 1999).

Operationalization of the Theoretical Framework

Social Capital Theory and Urban Decay were operationalized alongside AAL factors to link theoretical concepts with observed impacts, as mentioned in Figure 1 and summarized in Table 1. Relationships, safety, and community connection were found to be adversely affected by low social capital, which was associated with increased fear and decreased community connection. Low social capital was manifested in poor neighborhood interaction, low trust, and weak cohesion. Lower SWB in terms of standard of living, health, and future security was associated with urban decay, as evidenced by visual blight, property value, vandalism, and public health. There impacts were also quantified in Tables 4 and 5. This connectivity demonstrated the mechanism through which abandoned railway landscapes affected the SWB. All relevant theoretical and empirical sources supporting this operationalization were discussed in the literature review. For further understanding, the conceptual linking table (Table 1) was provided.

Conceptual model of linking abandonment, neoliberal policy, and SWB

Figure 1 illustrated how neoliberal urban policies contributed to the formation of AALs. The connection between neoliberalism, abandonment, and SWB was articulated within the conceptual model. Their relationship was illustrated clearly. After listing the impacts of AALs and categorizing them with theories and literature review, the impacts of AALs were categorized under three primary dimensions: social, emotional, and physical impacts. Due to the limited time available for the study, only six AAL impacts (highlighted in Figure 1) were selected as independent variables.

METHODOLOGY

Research design

Upon further exploration, Figure 2 illustrates a theory-driven approach to the research, presenting a clear and convincing foundational argument that addresses ROs 3 and 4. In terms of local identity impacted by neoliberal policies, it examined the variables of independent, control, and dependent variables to determine which AALs had an impact on QOL under neoliberal pressure.

Data Collection Methods and Tools

Visual recordings, site inspections, and semi-structured interviews were used to collect the pertinent data. By recording the physical circumstances, site observations were employed to understand how locals interacted with these areas. A total of 50 residents were selected as the sample.

Sample selection criteria were based on,

- Participants were required to be permanent residents living within the immediate vicinity of the railway premises who were directly affected by AAL impacts. The 600 m spatial boundary was determined based on principles of walkability and visual exposure (Figure 3). It had represented the typical distance residents could comfortably walk within their neighborhood.

- An equal number of male and female respondents (25 each) were selected to avoid gender bias in perceptions of SWB and community interaction.

- Respondents were chosen from a range of age groups (18-30, 31-40, 41-50, and over 51 years) to capture generational variations in perceptions and experiences.

- Participants represented different residential durations (1-5 years, 6-10 years, 11-20 years, and more than 20 years) to incorporate perspectives of both long-term and recent residents.

Table 1: Conceptual linking table to operationalization of the theoretical framework.

Theory	Indicator (Operationalization)	AAL Facor	SWB Domain (PWI-A)	Observed Impact/Mechanism
Social capital theory	Community interaction, trust, coheion	Fear, community connection	Relationships, community connection, safety	Weak social capital → higher fear lower trust → reduced SWB in relationships, safety and community domains
Urban decay (spirals of decline, broken windows)	Physical nelect, visual blight, vandalism	Property value, visual blight, vandalism, public health, violent crims	Standard of living, health, safety, future security	Neglected spaces → visual blight, property depreciation, crime → stress and dissatisfaction → lower SWB scores

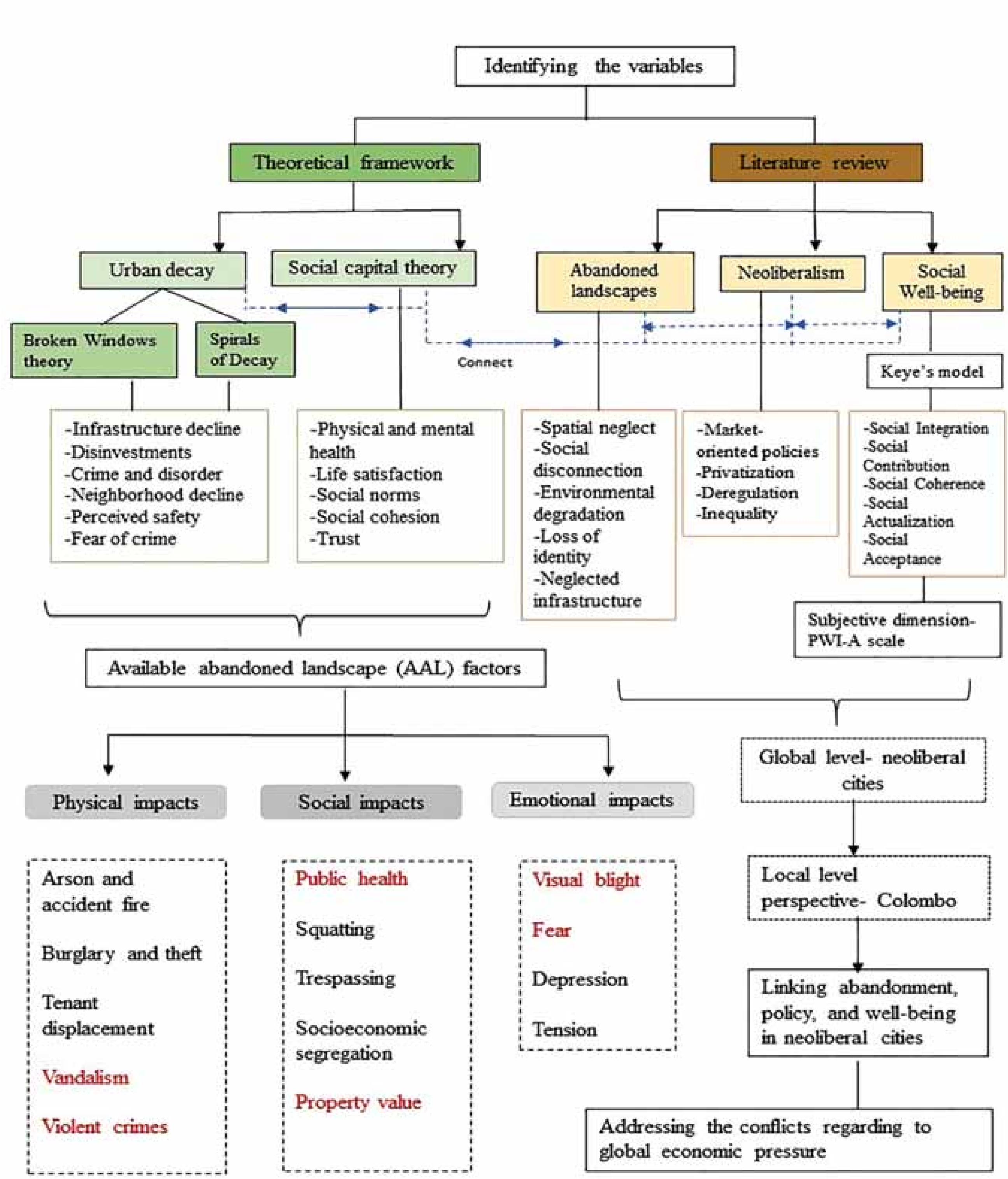


Figure-1: Conceptual model.
Source: Compiled by Author)

Participants were fully informed about the study, provided voluntary consent, and were assured of anonymity and confidentiality to ensure ethical integrity. They could withdraw at any time without consequence, in accordance with standard ethical guidelines for human research. To collect data, two types of questionnaires were used as follows.

1. A researcher-designed questionnaire was employed to assess the impacts of AAL variables, namely, public health, property values, visual blight, fear, violent crime, and vandalism. The residents' level of satisfaction regarding each AAL variable was measured using a Likert scale, through which respondents rated their perceived level of satisfaction.

2. The Personal Well-being Index-Adult (PWI-A) scale was used to define and assess subjective well-being and QOL of participants aged 18 years and older. The scale was completed verbally or in writing, and participants are expected to complete the items independently. The seven satisfaction questions that made up the PWI-A encompass standard of living, health, achieving in life, relationships, safety, community connection, and future security (Figure 2). Each question represented a QOL domain (International Well-being Group, 2024).

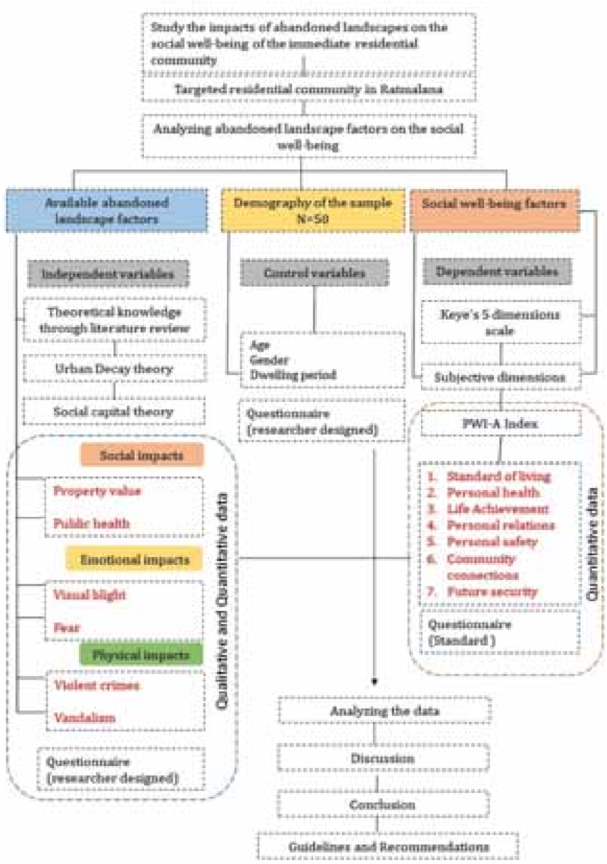


Figure-2: Research design.
Source: Compiled by Author)

During the preliminary interactions, participants expressed difficulty distinguishing among the 10-point response options. However, PWI-A is typically administered using a 0-10 scale, and here the scale was adapted to a 5-point format to accommodate the low literacy levels, limited survey experience, and cultural tendencies of the community who preferred to maintain their anonymity.

Defining parameters and measuring

Six AAL factors were selected as independent variables, and SWB was measured using the PWI-A, which assessed satisfaction in seven domains (Figures 1 and 2). The PWI-A was adapted to evaluate SWB in the context of living near AALs. An author-designed questionnaire was used to measure AAL impacts as the dependent variables (Figure 2). Satisfaction levels were rated on a 5-point Likert scale, where respondents indicated their level of satisfaction from 1 (Strongly Disagree) to 5 (Strongly Agree). The identities of respondents were not disclosed or used for any other purpose, in adherence to established ethical principles.

Data clearing and scoring

SWB factors and QOL measures according to Eq. 1.

$$\frac{X - k^{min}}{k^{max} - k^{min}} \times 100$$

The "triage" approach to subjective well-being formalizes a method for assessing and prioritizing individual well-being levels (Weinberg, et. al., 2018) as follows,

- Scores between 70 and 100pp = Well (W: normal homeostatic control)
- Scores between 50 and 69pp = Under Well (UW: challenged homeostatic control)
- Scores between 0 and 49pp = No Well (NW: defeated homeostatic control)

Mixed-Methods Integration

The study used a triangulation mixed-methods design that brought together both numerical and descriptive forms of data. Using more than one type of data helped strengthen the credibility of the results. Quantitative data were collected through the PWI-A survey, which explored overall SWB as well as specific life areas (Figure 2). To give context to these results, participants also shared their experiences through interviews, field visits, and photographs that captured their daily environments as quantitative data. The qualitative material was then linked with the PWI-A domains through thematic analysis and mapping, allowing comparisons between where the two sets of findings agreed or differed.

Abandoned railway premises at Ratmalana, Colombo - Case Study

Introduction

This case study examined the impacts of AAL on the SWB of the immediate residential community in Ratmalana, an industrial zone located 14.6 kilometers south of Colombo, within the Dehiwala-Mount Lavinia Municipal Council (DMMC) administrative boundaries (Figure 3 and Table 2). Ratmalana was purposively selected as the case study due to its strategic significance to Colombo its long standing exposure to AAL Related Disturbances and the pressing need to understand and mitigate the associated effects on the surrounding community.

Table 2: Details of the site.
Source: Compiled by Author.

S. No.	Space	Area (sqm)	Special notes
1	Abandoned carriageways	12000	Inside an abandoned landscape within the railway premises
2	Abandoned open spaces	7000	
3	Abandoned railway yard	20600	
4	Abandoned railway line	1700	
5	Outside abandoned places	13504	Outside, open abandoned landscapes
6	Station road	-	Streets
7	Galle road	-	
8	Residential area	-	

Privatization, market-driven development, and industrial decentralization, areas like Ratmalana faced increased risks of environmental degradation, spatial inequality, and landscape abandonment under neoliberal urban policies. Although the area was classified as an industrial zone and was planned for relocation to the Horana and Ingiriya industrial zones under the 2030 Colombo Structure Plan. It could have resulted in an excessive number of firms, potentially degrading the environment and leading to landscape abandonment. The purpose of this study was to determine which aspects of Ratmalana have an impact on the SWB of the residential community, linking broader neoliberal processes to local socio-spatial outcomes.

Demographic Details

An overview of the demographic information for Ratmalana was provided in Table 3 and Figure 4, highlighting essential elements that emphasized the impacts of AALs on SWB. These elements created the framework for understanding how social dynamics and physical surroundings interacted within the Ratmalana community.

DATA PRESENTATION, ANALYSIS, AND DISCUSSION

Demographic Profile of Respondents

The relatively small sample size was determined by time and accessibility constraints. It was carefully chosen to provide highly relevant insights into community perspectives. To ensure diversity in viewpoints and experiences, the sample included respondents of varying gender, age, and dwelling period characteristics (Figure 5).

Analyzing the AAL Impacts

The analysis of satisfaction scores highlights the negative impacts of AALs on the community (Figure 6 and Table 4).

- Property Values: 44% of respondents believed AALs contributed to the decline of property values. Participants often mentioned that AALs reduced the attractiveness of surrounding areas and discouraged new investment. This

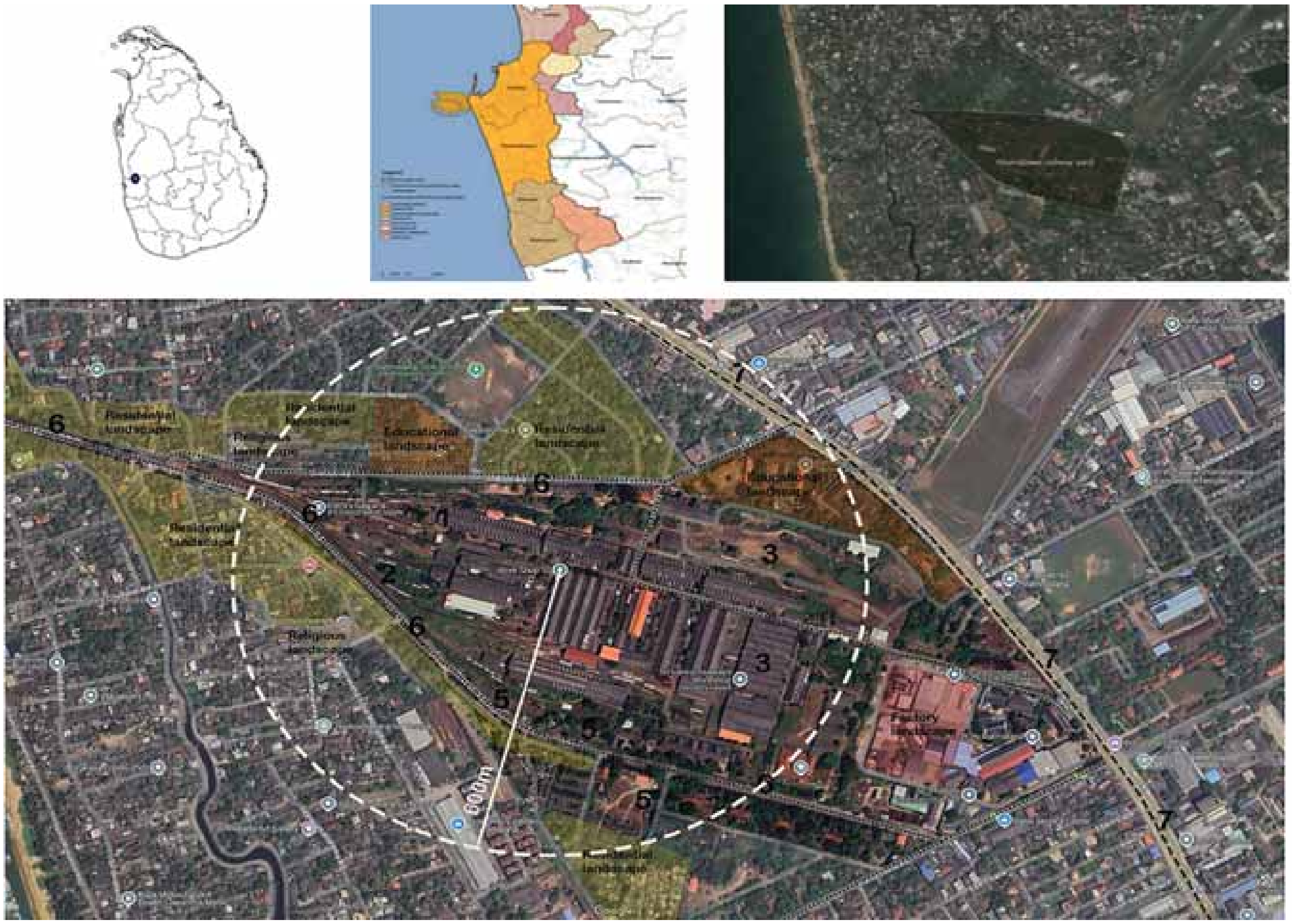


Figure-3: Context and location..

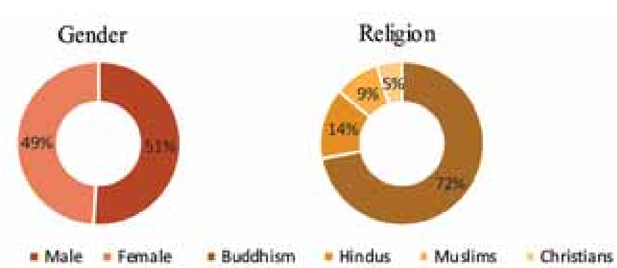


Figure-4: Demographic details.
Source: DMMC development plan 2021-2030.

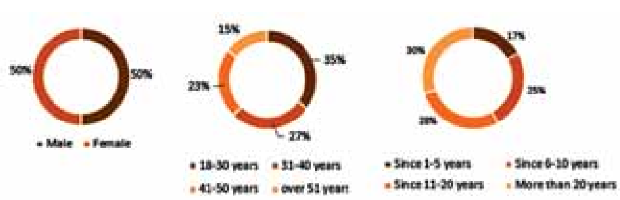


Figure-5: Range of the gender, age, and dwelling period of respondents.
Source: Compiled by Author.

pattern reflected the Spiral of Decline theory, where visible neglect gradually weakened the economic stability of a neighborhood.

- Public health: 38% of those interviewed were extremely dissatisfied, citing stagnant water, waste buildup, and inadequate sanitation as the main health risks. These issues within the study area were validated by observations made during site visits. The results demonstrated how environmental degradation can impact health outcomes in Ratmalana and were consistent with the Urban Decay framework.
- Visual Blight: Dissatisfaction was highest for visual blight (66%, mean score = 2.12), characterized by overgrown vegetation, derelict landscapes, and litter. This supported the Broken Windows theory, suggesting that visible neglect generated psychological discomfort and community disengagement.
- Fear and Safety: 42% reported dissatisfaction with safety, and 28% expressed fear. Interviews revealed that concerns about crime and poor lighting eroded a sense of

Table 3: Demographic details of the selected context.
Source: Dehiwala Mount Lavinia Development Plan 2021-2030.

Data	Details	Special notes
Population	Population	38,930
	Population density	216 person/ha
	Population prjection (2025)	58,700
Occupation	Families engage in fishing	569
	Labor force	21,800 (56%)
Housing	Houses in underserved settlements	45%
Vandalism	Theft reported	2532
Daily commuters	Number of daily passengers across the context	298,000
	Daily visited by local and foreign tourists	2170
	Number of commuters arriving/day (Train)	4000

Table 4: Mean values of the satisfaction level of AAL factors.
Source: Compiled by Author.

AAL Factors	Mean Scores
Property values	2.20
Visual blight	2.12
Fear	2.64
Violent crimes	2.20
Vandalism	2.94

security and social trust, indicating weakened social capital.
• Vandalism: 32% of respondents (mean = 2.94) disagreed with statements that were positive about the neighborhood. Graffiti, damaged fences, and property defacement were frequently mentioned as persistent problems, reinforcing perceptions of disorder and ongoing community decline.

Analyzing the SWB factors

According to an analysis of SWB variables in line with RO 3 (Table 5 and Figure 7), the existence of AALs significantly lowers QOL in several well-being domains.
• Standard of Living (mean = 2.42): Insufficient infrastructure, limited access to services, and diminished economic opportunities were cited by nearly half of the respondents (50%) as reasons for their discontent with their living circumstances. Merely 20% agreed with affirmative statements regarding living standards, indicating unequal neighborhood development and spatial inequality.

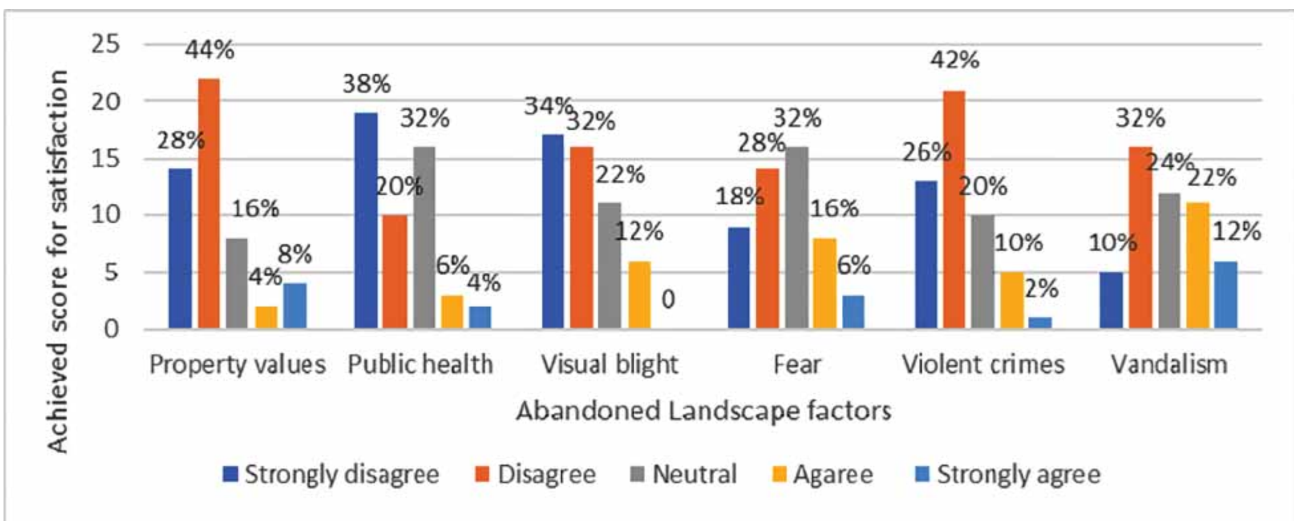


Figure-6: Achieving scores of AAL factors.
Source: Compiled by Author.

Table 5: Mean values of the satisfaction level of SWB factors.
Source: Compiled by Author

Domain	Mean (1-5)	Converted (0-10)	Percentage Points (pp)	Triage Category
Standard of living	2.42	3.55	35.5	No Well (NW)
Health	2.6	4.0	40.0	No Well (NW)
Achieving in life	2.72	4.3	43.0	No Well (NW)
Relationships	2.66	4.15	41.5	No Well (NW)
Safety	2.38	3.45	34.5	No Well (NW)
Community-connectedness	2.5	3.75	37.5	No Well (NW)
Future security	1.86	2.15	21.5	No Well (NW)

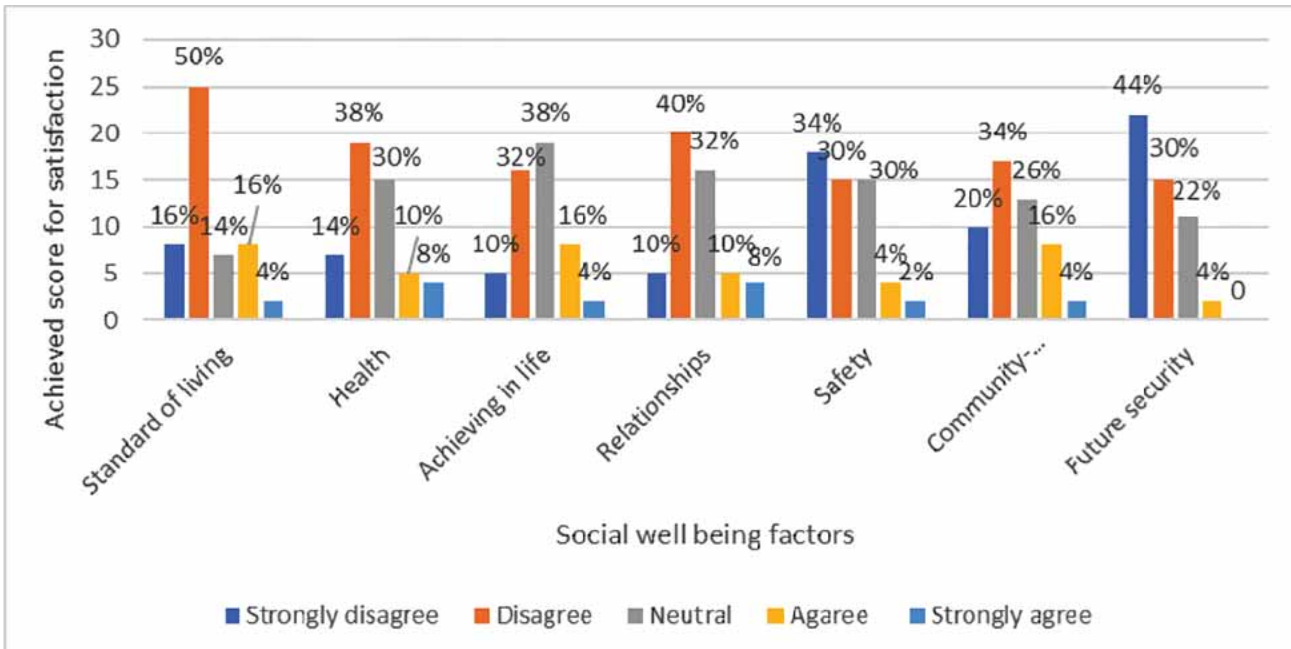


Figure-7: Achieving scores of SWB factors.
Source: Compiled by Author.

• Health (mean = 2.60): 38% of respondents disagreed with statements about health, despite some respondents expressing satisfaction. According to the Urban Decay framework, the main issues were pollution, standing water, and unclean surroundings. The limited capacity of residents to address these environmental issues further illustrates reduced social capital.

• Life Achievement (2.72) and Relationships (2.66): These dimensions showed moderate dissatisfaction (42% and 40%, respectively). Respondents indicated that marginalization, limited social interaction, and poor community networks restricted both personal development and emotional support, illustrating the erosion of social capital. These findings directly reflected Social Capital Theory, as low social cohesion and trust decreased access to social and emotional resources, which in turn led to SWB.

• Safety (2.38) and Community Connectedness (2.50): The most important results were related to feelings about safety and how connected they are to their community. A notable 64% expressed feelings of insecurity, and 34% reported weak social connections. Broken Windows Theory suggested that visible disorder increased feelings of fear and isolation, which was observed with neglected

Table 6: Effects of Gender and Age Group on Visual Blight and Vandalism.
Source: Compiled by Author

Cases	df	Approx. F	Trace $_{Pillai}$	Num df	Den df	p
(Intercept)	1	251.658	0.925	2	41.00	<.001
Gender	1	0.387	0.019	2	41.00	.681
Age-Group	3	1.036	0.138	6	84.00	.408
Gender * Age-Group	3	0.206	0.029	6	84.00	.974
Residuals	42					

Table 7: Effects of Dwelling Period and Age Group on Visual Blight and Vandalism.
Source: Compiled by Author

Cases	df	Approx. F	Trace $_{Pillai}$	Num df	Den df	p
(Intercept)	1	257.047	0.924	2	42.00	<.001
Dwelling Period	3	0.121	0.017	6	86.00	.994
Age-Group	3	1.174	0.151	6	86.00	.328
Residuals	43					

Table 8: Effects of Gender and Age Group on Achieving in life and community connectedness.
Source: Compiled by Author

Cases	df	Approx. F	Trace $_{Pillai}$	Num df	Den df	p
(Intercept)	1	336.097	0.943	2	41.00	<.001
Age-Group	3	1.438	0.186	6	84.00	.210
Gender	1	0.999	0.046	2	41.00	.377
Age-Group * Gender	3	0.988	0.132	6	84.00	.439
Residuals	42					

spaces, overgrown lots, abandoned buildings, and unlit pathways.

- Future Security (1.86): This area received the lowest score, indicating that people are uncertain about the future. Social Capital Theory suggested that communities with low social cohesion were less able to mobilize resources and support systems, contributing to anxiety and lost hope regarding future stability.

Overall, the results supported the idea that AALs played a role in community decline, both socially and physically. The low mean values for safety, community connectedness, and future security highlight urgent urban intervention priorities, such as better lighting, maintenance, and community engagement initiatives. Both actual community dissatisfaction and contextual response behavior were reflected in the relatively low mean PWI-A scores, such as Visual Blight (2.12) and Future Security (1.86), as mentioned in Tables 6 and 7.

Despite being numerically lower than the typical PWI-A benchmarks, these values were consistent with the modified 5-point scale and the self-reporting cautions. The community was classified as "No Well-being" (NW) due to the overall SWB mean of 36.2 pp, which is equivalent to 36% on the PWI-A scale after using Eq. 1. This indicated a breakdown of homeostatic resilience consistent with long-term environmental and social neglect.

Interpretation of Correlation Findings

The connections between AAL and SWB factors were depicted in the correlation matrix (Figure 8). The findings suggested that lower property values were linked to higher perceived insecurity and crime incidence, as evidenced by the negative correlations found between property values and violent crimes ($r = -0.212$) and fear ($r = -0.336$). On the other hand, a slight positive correlation was observed between property values and health ($r = 0.274$), suggesting

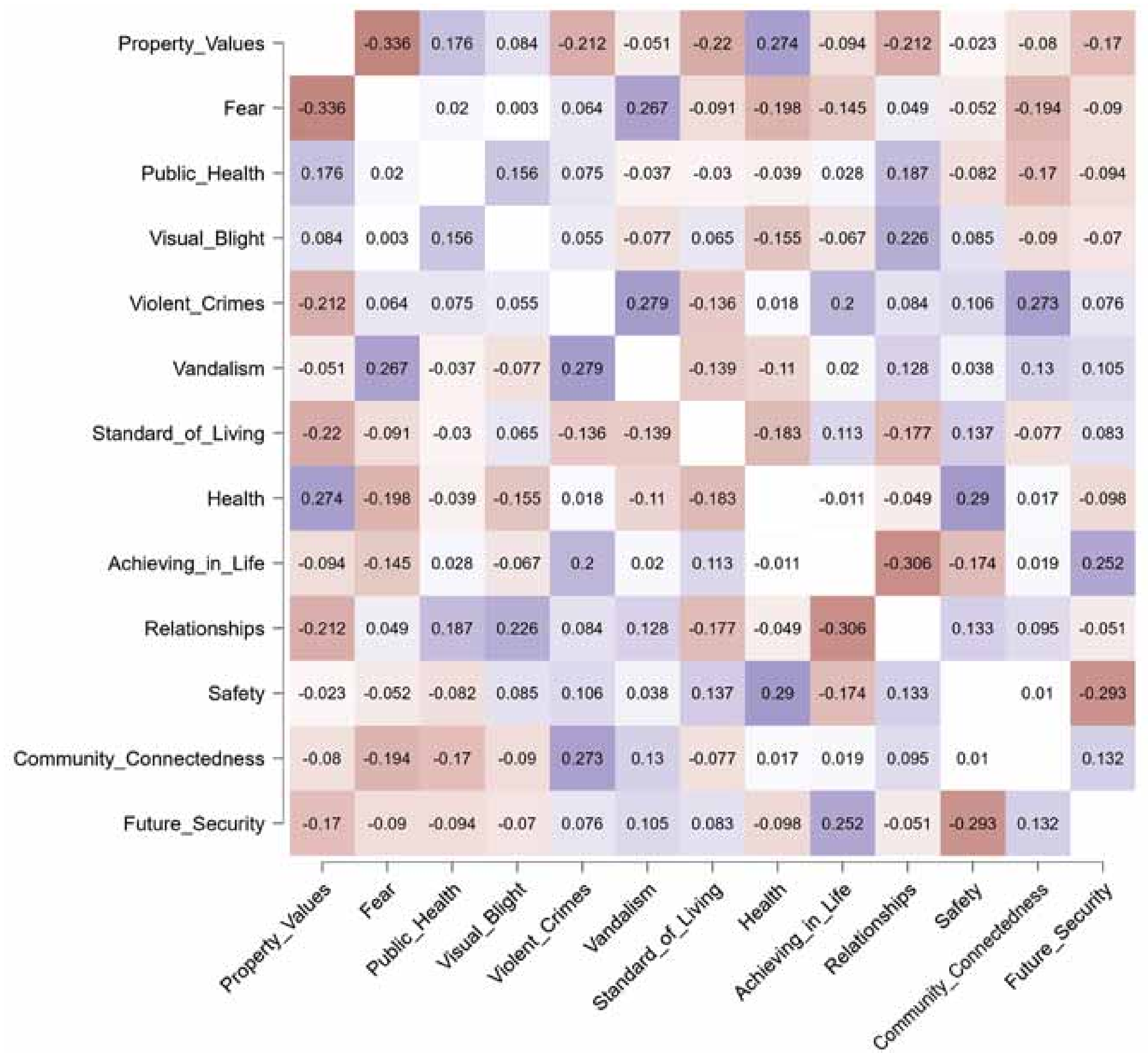


Figure-8: Heatmap of correlation analysist.
Source: Compiled Author.

Table 9: Effects of Dwelling Period and Age Group on Achieving in life and community connectedness.
Source: Compiled by Author

Cases	df	Approx. F	$Trace_{Pillai}$	Num df	Den df	p
(Intercept)	1	318.933	0.938	2	42.00	<.001
Age-Group	3	1.339	0.171	6	86.00	.249
Dwelling Period	3	0.742	0.098	6	86.00	.617
Residuals	43					

Table 10: Recommendations and future projection.
Source: Compiled by Author

Recommendation Aspect	Guidelines
1 . Policy Recommendations	
Urban policy reform	Incorporate subjective well-being (SWB) indicators into urban planning to identify areas most affected by AALs, monitor progress, and evaluate interventions. Policies should aim for equitable, inclusive growth, mitigating marginalization caused by AALs.
	Enforce maintenance standards for both industrial and residential areas to prevent visual blight, property depreciation, and environmental degradation, in line with the Broken Windows and Urban Decay frameworks.
	Prioritize infrastructure improvements, public services, and social programs in neglected neighborhoods to counter spatial inequality highlighted in the study.
Adaptive reuse and regeneration	Implement adaptive reuse of abandoned railway landscapes through community-led initiatives, such as small parks, recreational spaces, or public amenities, to reduce visual blight and enhance neighborhood aesthetics. This approach reduces visual blight, interrupts the Spiral of Decline, and improves neighborhood aesthetics and resident SWB. Promote Community Land Trusts (CLTs) for collective ownership in abandoned sites to prevent speculative land use.
Crime and safety mitigation	Introduce community policing, safety audits, and public lighting improvements in abandoned areas to reduce fear of crime and improve perceived safety, consistent with the Broken Windows Theory.
Community Engagement	Encourage resident participation in planning and maintaining regenerated spaces, fostering social capital, ownership, and cohesion within affected communities. Employ Participatory Budgeting (PB) at the municipal level to empower citizens to allocate funds for local regeneration projects
Balanced Urban Development	Promote equitable urban investment, ensuring neglected areas receive attention comparable to upscale districts, including infrastructure improvements, public services, and social programs. This approach counters unbalanced urban growth highlighted by Urban Decay frameworks. Apply Public-Community Partnerships (PCPs) for the co-management of abandoned landscapes between local authorities and community organizations
Public-Private Partnerships	Facilitate collaborations with private developers and local businesses to invest in sustainable redevelopment of abandoned areas, offering incentives for projects that enhance social and environmental outcomes.
2. Future Research Directions	Examine the long-term impacts of AALs on mental health, community development, and overall well-being.
	Employ advanced statistical techniques, such as regression or correlation analysis, to analyze a larger sample size.
	Could expand the sample size and include comparative cases across multiple sites to enhance statistical robustness and generalizability
	Expand research to multiple abandoned railway corridors across Sri Lanka to compare socio-spatial neglect and validate findings across diverse contexts.
3. Key Considerations	Prioritize public spaces and their maintenance, promoting social cohesion.
	Tackle economic and social disparities contributing to AALs' creation and exacerbation

that better property conditions might have been associated with better health perceptions.

There are consistent links observed between physical disorder and social instability, as evidenced by the weak positive correlation between fear and Vandalism (r = 0.267) and the moderate correlation between Vandalism and Violent Crimes (r = 0.279) among SWB indicators. Internal consistency among the well-being dimensions was evident, as shown by the weak-to-moderate positive correlation (r = 0.252) between relationships and life achievement. Overall, the correlation results supported the larger framework of environmental quality influencing community satisfaction. They showed that lower perceptions of safety and SWB tend to co-occur with degraded physical environments marked by vandalism, crime, and declining property values.

Multivariate Analysis of Demographic Influences

The effects of gender, dwelling period, and age group on perceptions of vandalism and visual blight were evaluated using a multivariate analysis of variance (MANOVA). Neither gender nor age group showed any significant major effects or interactions, according to the results (Table 6). Perceptions of vandalism or visual blight were not significantly impacted by age group or dwelling period when gender was considered (Table 7). Similarly, neither age group nor dwelling period significantly affected achievement in life or community connectedness (Table 8), and neither gender nor age group had any effect on these outcomes (Table 9).

CONCLUSION AND FUTURE PROJECTIONS

The research primarily highlighted the detrimental impact of AALs on the SWB of residential communities. It also emphasized the role of neoliberal urban policies in creating and exacerbating the issue of AALs, ultimately contributing to the social and economic marginalization of communities.

Significant findings are

- Resident well-being was significantly reduced in areas affected by AALs.

- Visual blight, heightened fear of crime, and declining property values were further exacerbated by AALs, worsening the QOL for residents.

- Residents had the greatest sense of uncertainty about their future among all the SWB standards. Life achievement and health remained below their ideal levels, but were comparatively less impacted.

- Lower property values were correlated with higher perceptions of insecurity and crime. Maintained properties were slightly associated with improved health perceptions, indicating the intertwined physical, economic, and social impacts of AALs.

- Limited social networks and weak community cohesion increased feelings of fear, isolation, and marginalization. These findings reinforce the relevance of Social Capital Theory, emphasizing that strong social relationships can decrease the negative effects of environmental neglect.

- Demographic factors such as age, gender, and dwelling period showed no significant influence on perceptions or SWB outcomes related to AALs.

- Neoliberal urban policies have contributed to the rise in abandonment, resulting in community marginalization.

- Unbalanced urban growth was evident in Colombo. Certain parts swiftly developed into upscale residential and commercial districts, while other regions deteriorated due to neglect and underinvestment

- Despite challenges, community engagement and social capital were found to mitigate some negative effects. It can be done particularly through participatory planning and localized interventions.

- Integrating SWB into urban planning was identified as a means to locate areas of greatest need, guide targeted interventions, and promote inclusive, human-centered urban governance.

The findings highlighted the need for a productive approach to addressing future projections (Table 10), which was identified as the primary outcome, and addressing research objective (4). In conclusion, the research demonstrated that the rise of AALs in Colombo reflects the damaging effects of neoliberal urban policies and unchecked market forces on SWB. The research highlighted the necessity for a paradigm shift in urban governance toward inclusive, community-centered, and welfare-oriented planning to enhance the QOL of residents.

EQ 1

X = The score or mean to be converted

k^{min} = The minimum score possible on the scale

k^{max} = The maximum score possible on the scale

REFERENCES

Abeyasekera, S., Maqsood, A., Perera, I., Sajjad, F. & Spencer, J., 2019. Discipline in Sri Lanka, punishment in Pakistan: neoliberalism, governance, and housing compared. *Journal of the British Academy*, 7(S2), pp.215–244. https://doi.org/10.5871/jba/007s2.215

Acioly, C.C., 1999. *Institutional and Urban Management Instruments for Inner City Revitalization: A Brief Review with Special Focus on Brazilian Experiences*. London.

Adams, G., Estrada-Villalta, S., Sullivan, D. & Markus, H.R., 2019. The psychology of neoliberalism and the neoliberalism of psychology. *Journal of Social Issues*, 75, pp.189–216. https://doi.org/10.1111/josi.12305

Armstrong, D., n.d. A survey of community gardens in upstate New York: Implications for health promotion and community development. *Health and Place*. [online] Available at: http://www.elsevier.com/locate/healthplace

Boden, M., 2011. Neoliberalism and counter-hegemony in the global south: Reimagining the state. In: S.C. Motta & A.G. Nilsen, eds. *Social Movements in the Global South: Dispossession, Development and Resistance*. London: Palgrave Macmillan UK, pp.83–103.

Brenner, N. & Theodore, N., 2002. Cities and the geographies of "actually existing neoliberalism". *Antipode*, 34(3), pp.349–379. https://doi.org/10.1111/1467-8330.00246

Bullock, J.M., Pywell, R.F. & Walker, K.J., 2007. Long-term enhancement of agricultural production by restoration of biodiversity. *Journal of Applied Ecology,* 44(1), pp.6–12. https://doi.org/10.1111/j.1365-2664.2006.01252.x

Corsaro, W.A., 2015. T*he Sociology of Childhood*. 4th ed. Thousand Oaks, CA: SAGE Publications, Inc. https://doi.org/10.4135/9781483399027

Cruwys, T., Haslam, S.A., Dingle, G.A., Jetten, J., Hornsey, M.J., Chonga, E.M.D. & Oeia, T.P.S., 2014. Feeling connected again: Interventions that increase social identification reduce depression symptoms. *Journal of Affective Disorders*, 159, pp.139–146. https://doi.org/10.1016/j.jad.2014.02.019

Falk, I.H. & Harrison, L., 1998. Indicators of Social Capital: Social Capital as the Product of Local Interactive Learning Processes. *CRLRA Discussion Paper Series*. [online] Available at: https://api.semanticscholar.org/CorpusID:151047740

Flora, C.B., 1995. Social capital and communities of place. *Rural Sociology*, 63(4), pp.481–506.

Gibson, C., Legacy, C. & Rogers, D., 2023. Deal-making, elite networks and public–private hybridisation: More-than-neoliberal urban governance. *Urban Studies*, 60(1), pp.183–199. https://doi.org/10.1177/00420980211067906

Handy, S., Cao, J. & Mokhtarian, P., 2006. Self-selection in the relationship between the built environment and walking. J*ournal of the American Planning Association*, 72(1), pp.55–74. https://doi.org/10.1080/01944360608976724

Harvey, D., 2005. *A Brief History of Neoliberalism*. Oxford: Oxford University Press. https://doi.org/10.1093/oso/9780199283262.001.0001

Holt-Lunstad, J., Smith, T.B., Baker, M., Harris, T. & Stephenson, D., 2015. Loneliness and social isolation as risk factors for mortality. *Perspectives in Psychological Science*, 10(2), pp.227–237. https://doi.org/10.1177/1745691614568352

International Wellbeing Group, 2024. Personal Wellbeing Index Manual: 6th Edition, Version 2, 190624. Geelong: Deakin University. Available at: http://www.acqol.com.au/publications#Open-access

Keyes, C.L.M., 1998. Social well-being. *Social Psychology Quarterly*, 61(2), pp.121–140. https://doi.org/10.2307/2787065

Korpela, K.M., Ylén, M., Tyrväinen, L. & Silvennoinen, H., 2008. Determinants of restorative experiences. *Health and Place*, 14(4), pp.636–652. https://doi.org/10.1016/j.healthplace.2007.10.008

Krupat, E., 1985. *People in Cities: The Urban Environment and Its Effects*. Cambridge: Cambridge University Press.

Lambin, E.F., Geist, H.J. & Lepers, E., 2003. Dynamics of land-use and land-cover change. *Annual Review of Environment and Resources*, 28, pp.205–241. https://doi.org/10.1146/annurev.energy.28.050302.105459

Leyden, K.M., 2003. Social capital and the built environment. *American Journal of Public Health*, 93(9), pp.1546–1551.

Lin, N., 1999. Social networks and status attainment. *Annual Review of Sociology*, 25, pp.467–487. https://doi.org/10.1146/annurev.soc.25.1.467

Lin, N., 2001. *Social Capital: A Theory of Social Structure and Action.* Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511815447

Lorenc, T. et al., 2012. Crime, fear of crime, environment, and mental health. *Health and Place*, 18(4), pp.757–765. https://doi.org/10.1016/j.healthplace.2012.04.001

Moser, S., 2015. New cities: Old wine in new bottles? *Dialogues in Human Geography*, 5(1), pp.31–35. https://doi.org/10.1177/2043820614565867

Morrison, W., 2013. Criminology. In: C. Hale, K. Hayward, A. Wahidin & E. Wincup, eds. *Criminology*. 3rd ed. Oxford: Oxford University Press, pp.3–22.

Müller, B., 2013. *Erosion der gesellschaftlichen Mitte*. Hamburg: VSA Verlag.

Peck, J. & Tickell, A., 2002. Neoliberalizing space. *Antipode*, 34(3), pp.380–404. https://doi.org/10.1111/1467-8330.00247

Perera, I., 2015. *Forced Evictions in Colombo: High-rise Living*. Colombo: Centre for Policy Alternatives.

Piketty, T., 2015. *The Economics of Inequality*. Cambridge, MA: Harvard University Press.

Prak, N.L. & Priemus, H., 1986. A model for the analysis of the decline of postwar housing. *International Journal of Urban and Regional Research*, 10(1), pp.1–7. https://doi.org/10.1111/j.1468-2427.1986.tb00001.x

Sennett, R., 1998. *The Corrosion of Character*. New York, NY: Norton.

Skogan, W., 2015. Disorder and decline: The state of research. *Journal of Research in Crime and Delinquency*, 52(4), pp.464–485. https://doi.org/10.1177/0022427815577836

Sousa Matos, R., 2014. Urban landscape: Interstitial spaces. *Landscape Review*, 13(1). https://doi.org/10.34900/lr.v13i1.794

Tomyn, A.J., Weinberg, M.K. & Cummins, R.A., 2015. Intervention efficacy among 'at risk' adolescents. Social Indicators Research, 120(3), pp.883–895.

Wakefield, S. et al., 2007. Growing urban health: Community gardening. *Health Promotion International*, 22(2), pp.92–101. https://doi.org/10.1093/heapro/dam001

Watson, V., 2013. Conflicting rationalities: Implications for planning theory and ethics. *Planning Theory and Practice*, 4(4), pp.395–407. https://doi.org/10.1080/1464935032000146318

Weaver, T.P.R., 2016. By design or by default: Varieties of neoliberal urban development. *Urban Affairs Review*, pp.1–33. https://doi.org/10.1177/1078087416683448

Weinberg, M. K., Webb, D. A., Gwozdz, W., & Cummins, R. A. 2018. Incentivised Online Panel Recruitment and Subjective Wellbeing: Caveat Emptor. *Journal of Wellbeing Assessment*, 2:41–55.

Wilson, J.Q. & Kelling, G.L., 1982. Broken windows: The police and neighborhood safety. *The Atlantic Monthly*, 249(3), pp.29–38.

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING
Volume 35 Issue 2
ISSN (P) 1728-7715 - ISSN (E) 2519-5050
Journal DOI: www.doi.org/10.53700/jrap_neduet
Issue DOI: www.doi.org/10.53700/jrap3522025

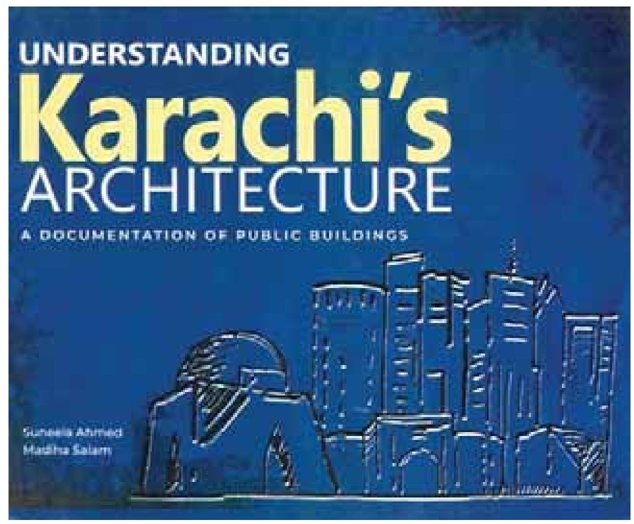
UNDERSTANDING KARACHI'S ARCHITECTURE; A Documentation of Public Buildings

Suneela Ahmed, Madiha Salam

A Review by Sarah A. Khan*

BOOK REVIEW

Globalization has played an important role in shaping the world in contemporary times. On one hand, cultural homogenization is transforming the world into a global village, and there is a rising concern about the preservation and continuation of local identity. This book, which addresses the ongoing global and local identity debate, is a generous contribution to literature for students, academics, researchers, and individuals. It focuses on the role of public buildings in establishing a city's visual identity and character, as well as the various forces, individuals, and institutions that influence this process. Understanding the contributors to Karachi's evolution is a challenging task in itself, and one may always struggle to define Karachi's architectural identity. Encountering the dearth of available literature on Pakistan's built form in general and Karachi in particular, this book establishes a reference point for understanding the evolution of Karachi's visual identity.



Dr Suneela Ahmed and Ms Madiha Salam, from the Department of Architecture and Planning at NED University of Engineering and Technology, collaborated on the book. Their full biographies can be found in the book, but they share a common interest in the social, political, and environmental influences at work in architectural and urban planning and in bridging the gap between academics, research, and practice.

The book's first appearance is very handy. The dedication is inclusive, encompassing everyone who has contributed to Karachi's rich diversity, and the acknowledgement pays tribute to all the individuals and institutions who have, knowingly or unknowingly, contributed to the city's academic and built landscape. The book is organized into two sections: theory and folios. Roughly 40% of the content is dedicated to the background, evolution, language, influences, and design paradigms of Karachi's public architecture, with the other 60% devoted to a portfolio of 80 notable public buildings in Karachi, organized chronologically.

Chapter One establishes the book's scholarly, pragmatic, and rational tone. The objectives clearly define the reasoning for the exercise, as well as how and in what ways this research may be useful to all professional architects, students, and academia. Chapter one presents a full summary of the book for the reader's convenience, brilliantly summarizing each chapter and its value to the reader. There is also a detailed description of the research methodology used for this study, which can be used as a reference for future researchers.

* Assistant Professor, Department of Architecture and Planning, NED University of Engineering and Technology, Karachi.
sarahkiran@gmail.com

Chapter two is a bittersweet account of Karachi’s built form, and the plural powers behind the regulation and control of its production. Chronologically organised, it discusses the effects of local power systems, both institutional and political, on who selects what gets built and what design vocabulary is used. The narrative is divided into three important sociopolitical eras in Karachi's history: Karachi as Pakistan's capital, the shift of capital to Islamabad, and Karachi as Pakistan's economic hub. The text includes the factors behind the formation of the city's image, design movements embraced as styles of expression, and key landmark buildings, as well as the social, political, and economic decisions behind this process. It discusses the incorporation of postmodernist theories into the local context, the Islamization of architectural imagery, and the shift in building typologies from public to cooperative and commercial, before concluding with a discussion of the creation of a new culture of capitalism, class, and consumption, as well as its expression in the dominant building typology in a global image clad in glass and steel.

Chapter three is a condensed literature review establishing a theoretical framework for comprehending the built form. This chapter contains several key terms and concepts influencing a city's aesthetics and values. The second portion of this chapter is a list of noteworthy buildings chosen based on the criteria outlined above. The matrix is organised chronologically, starting with structures built in 1928 and progressing through ongoing projects in 2023, including the building's name, design paradigm, typology, date of construction, and the designer architect/firm. The matrix depicts a diverse paradigm of architectural styles in Karachi ranging from Classical Art Deco, Bombay Style, Mannerism, Modern, Early Modernist, Modernist, Post-Modernist, Regional Modernist, Regionalist, Critical Regionalist, Regional, Regional Manifestation, Regional Modern, and Islamic Architecture Influence, establishing a visual vocabulary for Karachi’s amenity, commercial, corporate, education, healthcare, hospitality, recreation, and religious architecture.

The third section is another rich trove of literature, debating the role of public buildings in developing an identity for the city, separated into two sections. The first section goes into great detail about the causes and consequences of the shift in the role of government institutions from decision maker to facilitator, with a highly influential private developer persuading and deciding what will be built and how, with no regard for the context's infrastructural and social realities. It offers a peek of the many theoretical paradigms that may be found in Karachi's built environment as the city seeks a visual identity. The last half of this chapter emphasizes the significance of localization in the construction of identity through public buildings, while also discussing the architect's responsibility, technology, materials, commercialization, and context in developing this identity.

Chapter four, along with the folios of 80 landmark public buildings, is a comprehensive account of all the public buildings constructed in Karachi from 1947 to date. It is the most important addition to the literature discussing individual buildings at length. This section is well composed to investigate the significant landmark public buildings erected during that period, the important architects and their design philosophy, major institutions overseeing public architecture, social and cultural paradigms, and their reflection in the built landscape. Several public constructions, including their planning, design, and construction, are thoroughly documented. The text is followed by a colorful portfolio of famous public buildings that includes images of the projects retrieved from the architect's archives, a summarized description of the building, the name of its architect, the date of construction, typology, location, and the construction style paradigm. Projects with architectural drawings are also featured, and others have a Google Earth image displaying their present footprint. This section will undoubtedly assist all architecture students and researchers in visually identifying famous buildings, reading their elevations and plans, and comprehending each project through the enormously rich description provided in Chapter Four.

The conclusion identifies major concerns about Karachi's public architecture, where most buildings are concentrated in the city center in modernist style and serve as a display of various aesthetics with no examples of green architecture or contextual revivalism. The corporate identity is currently taking over, demonstrating the presence of global capital looking for investment opportunities. It also highlights the importance of an urban design statutory body and bylaws for the design of built form at the urban design scale.

Finally, this significant publication extensively tackles the formally planned built form of Karachi, particularly public buildings, the impact of local power structures on what is built and how, and an extensive categorization of the buildings into a matrix highlighting various in paradigm, typology, and lists the architect and date of construction, as well as debating the role of public buildings in developing a city identity. The bibliography at the end is a comprehensive account of all the reference material available on public architecture, particularly Karachi architecture; however, the book lacked a detailed glossary of terms and concepts used in the discourse, which I found lacking as a reader. The book cover could have been a better representation of Karachi's rich diversity of architecture, but since they don't judge a book by its cover, the book is worth reading and a significant contribution to literature, and it is highly recommended to all professional architects, students, and academia.

This review was published as “NON-FICTION: KARACHI’S BUILT FORM” in Dawn EOS, https://www.dawn.com/news/1767448 on July 29, 2023

Journal of Research in Architecture and Planning

Journal of Research in Architecture and Planning is the official journal of NED University of Engineering and Technology, Karachi. The Journal publishes two volumes biannually. The primary aim of the Journal is to provide an international forum for the dissemination of research and new development in architecture, planning and urban design. The Journal presents advanced knowledge and new research contributing towards enrichment and growth of the profession.

SUBSCRIPTION INFORMATION

One year (2 issues) paid subscriptions for each section of to **Journal of Research in Architecture and Planning** are available at following rate:

☐ For Pakistan Rs. 500/- ☐ Rest of the World US$ 50/-

Single issue of Journal can be purchased at the following rate:

☐ For Pakistan Rs. 250/- ☐ Rest of the World US$ 25/-

ADDRESS INFORMATION:

First Name________________________________Last Name ____________________________

Title _________________________Company____

Department ____

Street Address ____

City ________________________State/Province ______________________________________

Country_____________________ Zip/Postal Code _____________________________________

E-mail Address ____

Please write your cheque/bank draft in favour of Chairman, Department of Architecture and Planning.

Online Transfers can be made:

Account No.: 495-8

Bank Name: National Bank of Pakistan

Branch: NED University Main Campus, Karachi

Swift Code: 1063

For Further Information Contact: jrap@neduet.edu.pk

JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING

INVITATION FOR PAPER CONTRIBUTIONS

ISSN 17728-7715 (Print), ISSN 2519-5050 (Online)
Listed in Ulrich Periodical Directory, "Y" category HJRS-HEC and Cross Ref.

Journal of Research in Architecture and Planning, an initiative of the DAP-NED, is published biannually. It aims to provide a medium for communicating research and critique in the broad domains of architecture and Planning, acting as a bridge between academics and practice. The JRAP is,

- completely **open access** with no charges with all its papers and volumes being downloadable.
- has **no article processing charges** for publishing
- is licensed with **Creative Commons**

Researchers, scholars, architects and planners are invited for research paper contributions for the forth coming journal volumes. Papers can be based on ongoing researches or analytical and hypothetical concepts related to relevant fields. Interested authors can refer to the Instructions to Authors Manual (http://www.neduet.edu.pk/arch_planning/NED-JRAP/guidelines.html) for all details of requirements, procedures, paper mechanics, referencing style and technical review process for submitted papers.

FORMAT

Article Size	5000 words to 7000 words (please consult the journal office in case you wish to send a longer article)
Page Size A-4	**Page Layout** Portrait
Font Style	Times New Roman
Font Size	11
Visuals	All visuals (photographs, direction maps, diagrams, Google maps etc.) shall be in Jpg/Tiff format with minimum 300 dpi resolution at actual print size, These shall be properly captioned and clearly referred in the text. Please do not insert them in the text.
Drawings	AutoCAD drawings shall be converted in tiff format with a readable size and legend.
Submission	Online submission may be done through the journal submission portal at www.onlinejrap.neduet.edu.pk.
Referencing System	Harvard Style

Previous issues of JRAP have covered following topics:

Townscapes	Vol. 1, 2001
Townscapes II	Vol. 1, 2002
Transportation in Architecture	Vol. 2, 2003
Conservation and Culture Heritage	Vol. 3, 2004
Form, Design and Details	Vol. 4, 2005
Urban Design Case Based: Theory and Practice(I)	Vol. 5, 2006
Urban Design Case Based: Theory and Practice(II)	Vol. 6, 2007
Architectural Education	Vol. 7, 2008
Architectural Practice	Vol. 8, 2009
Architecture for Housing	Vol. 9, 2010

Later Biannual issues from 2011-2022 have covered varying topic range:

- Architectural philosophy
- Architectural history
- Building conservation
- Building integrated renewable energy technologies
- Conservation led urban regeneration
- Eco-housing, Interactive architecture
- Land use planning
- Low carbon impact buildings
- Secondary cities
- Sustainable architecture
- Urban ecology/ Urban renewal / Urban sprawl
- Urban sustainablity / Urban transportation
- Urbanization

BOOK REVIEW: Contributions for our 'Book Review' section are welcome in the form of a brief summary and a sample of the publication related to the field of archiecture, planning and development.

For Further Information, please write to JRAP Editor
Dr. Masooma Shakir at jrap@neduet.edu.pk

City Campus | Maulana Din Muhammad Wafai Road, Karachi - 74200 PAKISTAN
Phone | (9221) 99213058 (9221) 32620793 **Fax** | (9221) 99213058 & 99261255
Email | jrap@neduet.edu.pk crd@neduet.edu.pk
Website | www.jrap.neduet.edu.pk

Department of Architecture and Planning,
NED University of Engineering and Technology,
University Road, Karachi-75270.
Tel: (92-21) 99261261-68 Fax: (92-21) 99261255
www.neduet.edu.pk
crd@neduet.edu.pk