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Comparative Analysis of Seismic Resistance and Cost Efficiency in Lift Core Construction Using Masonry Wall-Column Systems and Shear Wall Systems

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Abstract
This research paper presents a comparative analysis of seismic resistance and cost efficiency in lift core construction using masonry wall-column systems and shear wall systems. High-rise structures' lift cores are crucial vertical conduits that provide the necessary structural stability. To support the best practices in building design and construction, the seismic performance and financial effects of various lift-core construction techniques are examined. The study compares the seismic resistance implied on a structure by lift cores built with masonry wall-column systems, which combine load-bearing masonry walls with reinforced vertical columns to lift cores built with shear wall systems, which rely on reinforced concrete to withstand lateral forces. Analytical modeling and simulation approaches are used to evaluate seismic performance in scenarios involving severe earthquakes. A variety of loads, including dead loads, live loads, partition loads, wind loads, seismic loads, and load combinations that were pursued in accordance with BNBC 2020 standards, have been applied to both types of structures. Four required metrics were evaluated for the analysis of both structures: storey drift, overturning moment, storey shear, and storey stiffness. Furthermore, a thorough cost study is performed to evaluate the two building systems' economic viability. Each method's associated material costs for the construction of the lift core are taken into account in the analysis. By conducting thorough research, we summarized that although masonry wall lift cores with columns at four corners act better resistant to seismic action, the Shear wall lift core system overall performed better as it is more economically feasible and it's decent resistant to seismic force. The findings of this study provide important insights into the trade-offs between seismic performance and cost efficiency when choosing lift-core construction techniques. The findings are intended to help engineers, architects, and developers make informed judgments about building safety and economic sustainability in seismically-prone places.

Keywords: Masonry Wall, Shear Wall, Lift Core, Storey Drift, Stiffness, Storey Shear, Overturning Moment, ETABS

1. Introduction

Lift cores are critical components of high-rise buildings, enabling vertical circulation and structural stability. Masonry wall-column systems and shear wall systems are two popular methods for building lift cores; each has advantages and disadvantages related to cost-effectiveness and seismic resilience.

Significant studies have been conducted on the seismic behavior of the shear wall and masonry structure. Reinforced masonry (RM) and reinforced concrete (RC) shear walls were compared across seismic hazard zones in Canada, revealing comparable material quantities and costs. Despite differences in seismic demands and structural properties, both materials exhibit similar economic viability for shear wall construction (El-Sokkary & Galal, 2020). Also, the UHPC method is cost-effective in comparison to high-strength concrete in the construction of tall buildings. UHPC grade: 185 MPa shows the best results in cost analysis and seismic performance (AlHamaydeh et al., 2022). Comparative research shows rocking walls outperform traditional RC walls in terms of damage resistance and self-centering properties, but are more affected by higher modes in terms of shear and bending moments, especially at higher intensities (Aragaw & Calvi, 2020). Researchers have pioneered hybrid soft-computing models for predicting the shear capacity of reinforced concrete shear walls, offering enhanced accuracy and reliability compared to traditional empirical models (Keshtegar et al., 2022). Meanwhile, the modular approach to high-rise construction introduces a paradigm shift by utilizing precast concrete modules as shear walls, challenging conventional methods and potentially reducing construction time and costs (Wang et al., 2020). The SC-RRCSW model is proposed by researchers which introduces an innovative seismic design approach, emphasizing repairable connections and the use of replaceable structural fuses to minimize damage. It exhibits high initial stiffness, substantial energy dissipation, and the potential for quick recovery after seismic events, offering promising prospects for practical implementation in various structures (Parsafar & Moghadam, 2017). Also, special RC shear walls significantly improve structural response compared to their ordinary counterpart with negligible impact on initial investment cost (Nader Aly & Galal, 2020). An investigation shows peripheral RC shear walls at the corners presented the smallest displacement and base shear compared to the other positions with hard soil (Al Agha et al., 2021). The available formulas for predicting shear amplification in ductile walls and dual systems (wall-frames) were presented in Rutenberg's research article (Rutenberg, 2013). Another research delves into the optimal positioning of lift core shear walls within multi-storied buildings, exploring configurations such as central placement versus edge or corner placement. Their analysis encompasses a comprehensive array of parameters, including displacement, story drift, mode frequencies, and participation, to assess the seismic response of different configurations (Saxena & Pahwa, 2018). Similarly, an investigation suggests the significance of lift cores in fortifying structures against seismic events of magnitude $M_w = 6.5$ or higher. Their study scrutinizes the influence of lift core location on seismic forces in buildings of varying heights and soil types, emphasizing the critical role of lift cores in seismic resilience (Shashwati Sanjay Vahadane & A. W. Yerekar, 2016). Torsional effects in L-shaped buildings with lift cores are scrutinized by Sushil Adhikari, who evaluates various models with lift cores positioned at different locations. Parameters such as drift ratio, displacement, and torsional irregularities are examined to gauge the structural response of L-shaped buildings to seismic loading (Adhikari et al., 2020). A research by Baral & Suwal focuses on the seismic performance of reinforced concrete buildings, investigating the impact of lift core wall positions and the inclusion of shear walls. Their research underscores the role of properly located shear walls in enhancing lateral stiffness, optimizing column design, and influencing architectural considerations (Baral & Suwal, 2023). Meanwhile, Botsa & Dasgupta's research explores the seismic capacity of five-story RC frame buildings concerning the placement of staircase and elevator core walls. Their findings from nonlinear static analysis highlight the significance of core wall orientation in determining lateral shear forces and structural stability (Botsa & Dasgupta, 2017).

This paper offers a comprehensive performance assessment of two G+10 storied residential buildings, one with a lift core built with masonry walls and columns at the four corners, and the other with shear wall lift core configurations in Bangladesh's most seismically active zone. ETABS 2019 version was used for modeling and analysis of the structures. CSiDetail 18 software was used for reinforcement calculation and building diagram drawings of different frame sections as well as isometric reinforcement diagrams of the structure. Load patterns and load combinations for this analysis were considered as per BNBC 2020 and lateral loads were assigned following Indian IS 875:2015 and IS 1893:2016 code. For four desired parameters- storey drift, overturning moment, storey shear, and stiffness, a comparative analysis was done for Structures with both types of Lift core models. Also, this study's evaluation includes cost estimation for both types of lift core models to identify the most cost-effective approach.

2. Methodology

For this study, a G+10-story commercial building was chosen. Two of the same structures were designed by ETABS software with two different types of lift core methods- one with masonry wall with four columns at four columns and connected beams (figure 1) and another one with reinforced shear wall (figure 2). For both of the designs, stability and balance were carefully considered, producing visually pleasing and robustly functional results. Each structure was created by meticulous planning and drafting with the proper integration of engineering principles. For both of the structural plans same number of columns and beams were used to emphasize enhanced acceptance through uniformity and optimized structural design. The dimensions for both structures were also kept the same 75' in length and 39' in width.

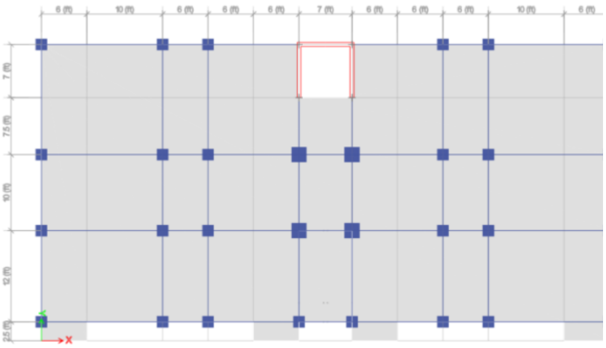


Figure 1: Structure with Shear wall lift core

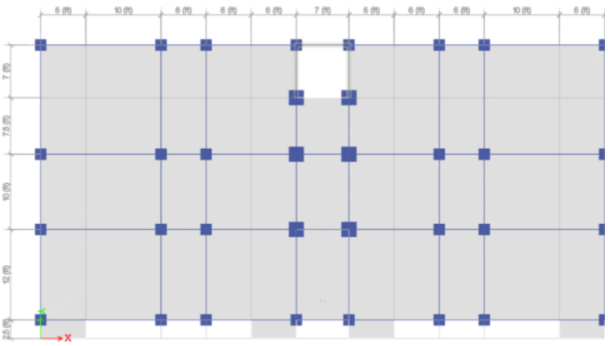


Figure 2: Structure with Masonry wall lift core

2.1 Material and Section Properties

In this Step, suitable material properties (Table 1) and section properties (Table 2,3) were chosen for both of the structures. However, the properties were kept the same for both structures.

Table 1: Material Properties

Name	Unit Weight, lb/ft^2	Modulus of Elasticity, lb/in^2	Grade
Concrete 4000psi	150	3604996.53	f'c=4000psi
Rebar 60,000psi	490	29000000	f'c=60000psi

Table 2: Frame Properties

Name	Material	Section Shape
Beam 1.5'x 1'	Concrete 4000psi	Concrete Rectangular
Great Beam 2'x 2'	Concrete 4000psi	Concrete Rectangular
Column 1.5'x 1.5'	Concrete 4000psi	Concrete Rectangular
Column 2'x 2'	Concrete 4000psi	Concrete Rectangular

Table 3: Shell Properties

Name	Material	Thickness, (in)
Shear Wall Lift 6"	Concrete 4000psi	6
Masonry Wall Lift 6"	Masonry 3000psi	6

Floor Slab 6”	Concrete 4000psi	6
Waist Slab 8”	Concrete 4000psi	8

At this point, the isometric view of structures was developed. In Figure 3 and Figure 4, the isometric view of structures is shown, and in Figure 5 and Figure 6, the elevation view is classified.

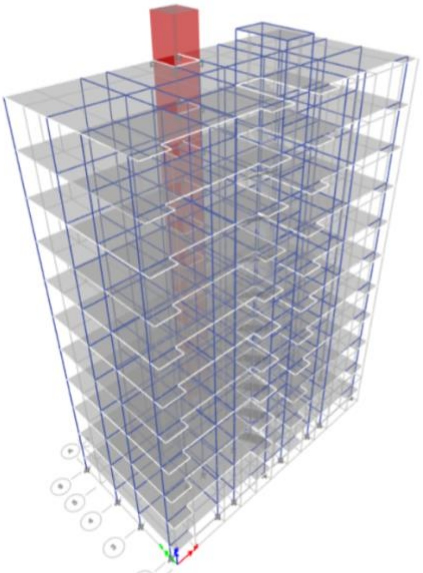


Figure 3: Structure-Shear wall lift core (Isometric View)

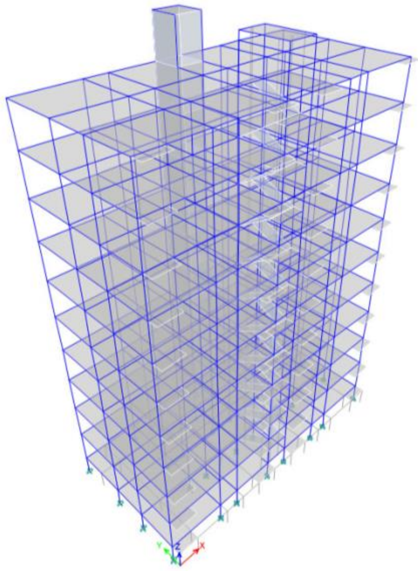


Figure 4: Structure-Masonry wall lift core (Isometric View)

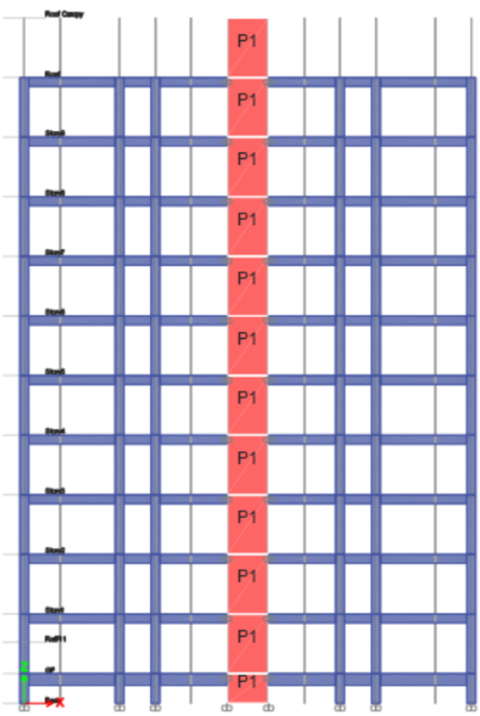


Figure 5: Structure with Shear wall lift core (Elevation)

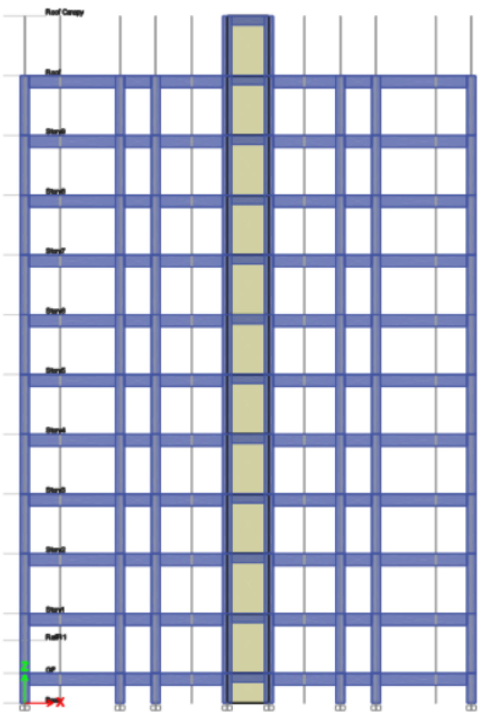


Figure 6: Structure with Masonry wall lift core (Elevation)

2.2 Assigning Supports, Pear level, Diaphragm, and Mass Source

At the base of the structure, the fixed restrain supports were assigned selecting all the columns. Pear level was assigned for shear wall section at the lift core. Then we assigned diaphragms selecting all the elements at every story level. Also, Mass Source for the structure after defining all loads.

2.3 Load Pattern and Load Combination

All the load configurations are first defined and then assigned. The loads in ETABS are defined using the static load cases command in the define menu by following the BNBC 2020. There are four types of loads- Dead load, Live load, Seismic load, and Wind load. Additional loads such as Partition load, and Floor Finish are sort of dead load which is classified as Super Dead load. For the seismic load, IS 1893:2016 code was used for load assignation in ETABS and for the wind load, IS 875:2015 code was used for load assignation in ETABS (Table 4) (Table 5). Then Load Combination was added following the BNBC 2020 (2.7.2.1 & 2.7.3.1, Page 3264-3265). Then Envelope load was assigned where all the combinations were added (Table 6).

Table 4: Load Patterns

Load	Type	Self-weight Multiplier	Auto Load	Types	Uniform Load Values	BNBC 2020 pages
Dead	Dead	1	Self-weight	---	---	
Live	Live	0		Typical upper floor	3.60 KN/m^2	536-544
				Stair slab	4.80 KN/m^2	
Floor Finish	Dead	0	---	For 150 mm thickness	3.54 KN/m^2	533
				For 203 mm thickness	5.14 KN/m^2	
Parapet Wall	Dead	0	---	---	0.066 kip/ft	---
Partition Load	Dead	0	---	Walls have no opening	0.22 kip/ft	---
				Walls with an opening	0.154 kip/ft	---
EQ_X	Seismic	0	IS 1893:2016	---	---	---
EQ_Y	Seismic	0	IS 1893:2016	---	---	---
Wind Load X	Wind	0	Indian IS 875:2015	---	---	---
Wind Load Y	Wind	0	Indian IS 875:2015	---	---	---

Table 5: Seismic Properties

Zone	Zone Coefficient	Wind Speed (m/s)
Zone-I (Rajshahi)	0.12	49.2
Zone-II (Dhaka)	0.20	65.7
Zone-III (Chittagong)	0.28	80.0
Zone-IV (Kurigram)	0.36	65.6

Table 6: Load Combinations

Sl. No.	Load Combination	Sl. No.	Load Combination
1	1.4DL	17	1.2DL +LL +0.3Ex - Ey
2	1.2DL+1.6LL	18	1.2DL +LL -0.3Ex + Ey
3	1.2 DL+LL	19	1.2DL +LL -0.3Ex - Ey
4	1.2DL +0.8 Wx	20	0.9 DL + Wx
5	1.2DL +0.8 Wy	21	0.9 DL + Wy
6	1.2DL -0.8 Wx	22	0.9 DL - Wx
7	1.2DL -0.8 Wy	23	0.9 DL - Wy
8	1.2 DL +LL + 1.6 Wx	24	0.823 DL + Ex + 0.3 Ey

Sl. No.	Load Combination	Sl. No.	Load Combination
9	1.2 DL +LL + 1.6 Wy	25	0.823 DL + Ex - 0.3 Ey
10	1.2 DL +LL - 1.6 Wx	26	0.823 DL - Ex + 0.3 Ey
11	1.2 DL +LL - 1.6 Wy	27	0.823 DL - Ex - 0.3 Ey
12	1.2DL +LL + Ex + 0.3 Ey	28	0.823 DL +0.3Ex + Ey
13	1.2DL +LL + Ex - 0.3 Ey	29	0.823 DL +0.3Ex - Ey
14	1.2DL +LL - Ex + 0.3 Ey	30	0.823 DL -0.3Ex + Ey
15	1.2DL +LL - Ex - 0.3 Ey	31	0.823 DL -0.3Ex - Ey
16	1.2DL +LL +0.3Ex + Ey		* DL = DL' + FF + PW

2.4 Analysis of Model

After checking the models, they were analyzed by the ETABS. The deformed shape for different load patterns and load combinations was displayed by the software. In Figure 7 and Figure 8, the deformed shape of both structures is shown for the absolute maximum “Envelope” loading condition in an isometric view.

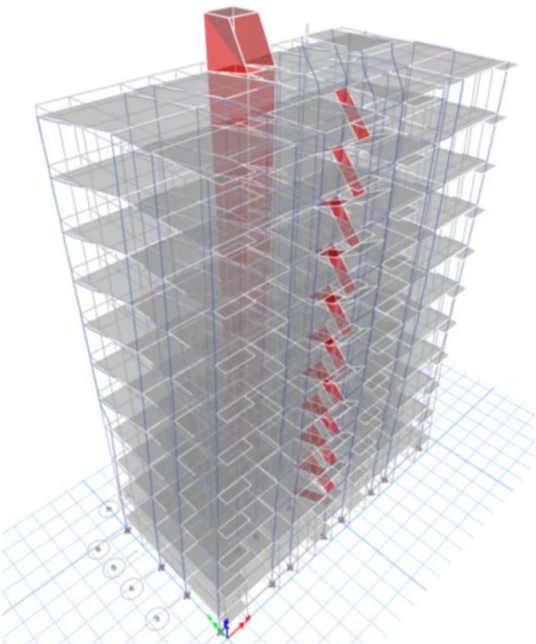


Figure 7: Structure with shear wall lift core: Deformed Shape

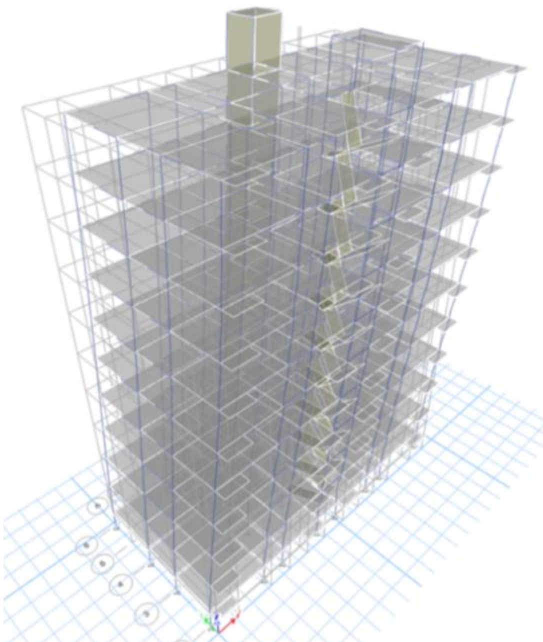


Figure 8: Structure with Masonry wall lift core: Deformed Shape

2.5 Design of Structures

In the design step, concrete frame, shear wall of lift core and slab were designed for both strictures. For the design of beam and column, the “Envelope” was chosen as the design combination. ETABS then showed the longitudinal reinforcement values for all frames in the structure. Then all failures were identified. For the design of Shear wall of the lift core, at first pier level was defined.

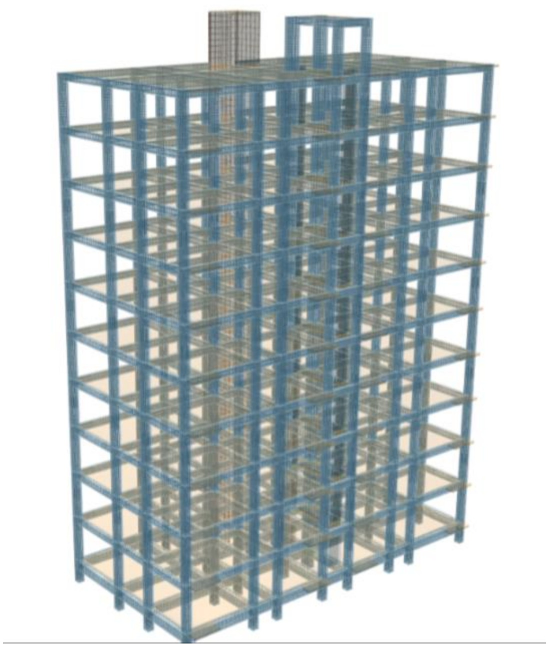


Figure 9: Structure with shear wall lift core: Rebar Diagram

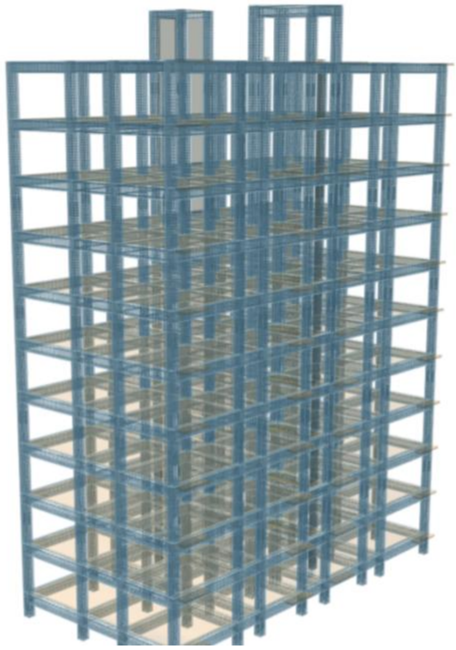


Figure 10: Structure with Masonry wall lift core: Rebar Diagram

By using "CSiDetails 18" software reinforcement details were found in diagram style. Here in Figure 9 and Figure 10, the rebar cases for all frames are shown in Isometric view for both structures. Figure 11 shows the reinforcement diagram for shear wall lift core isometric section separately and Figure 12 shows the maximum stress diagram of the shear wall lift core.

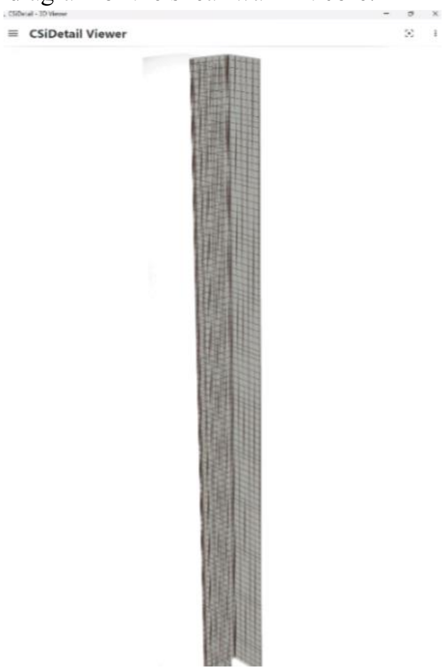


Figure 11: Reinforced Shear wall: Rebar Diagram (Isometric View)

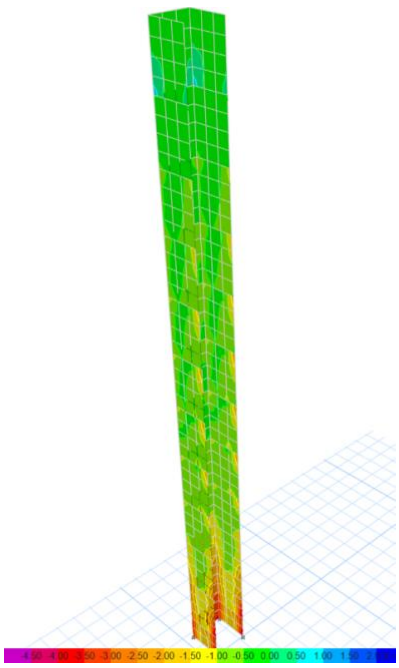
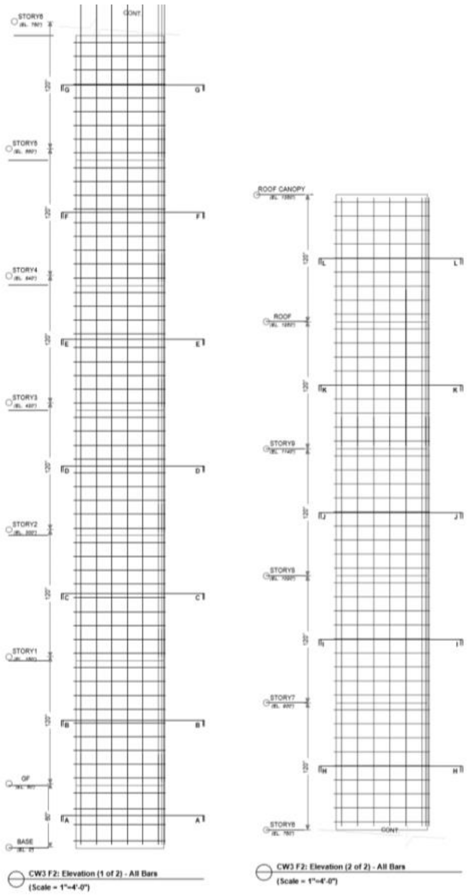


Figure 12: Reinforced Shear wall: Stress Diagram (Isometric View)



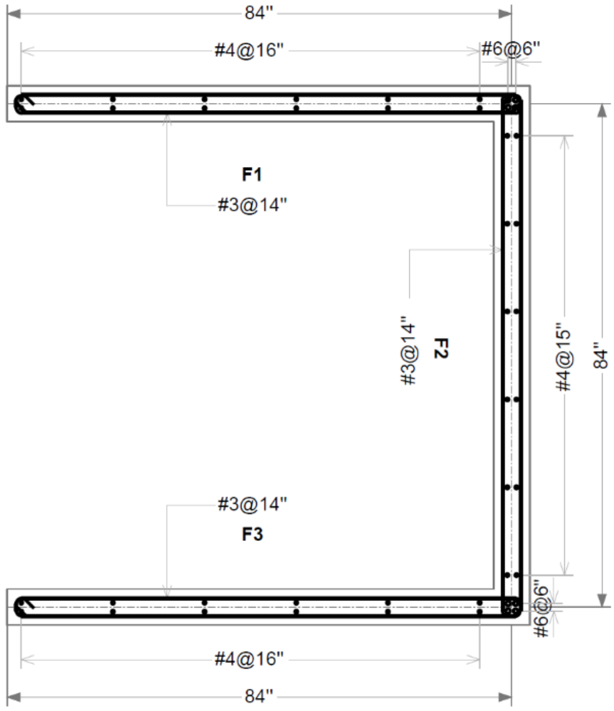


Figure 13: Rebar Diagram of Shear Wall (Elevation) Figure 14: Rebar Diagram of Shear Wall (Section View)

Here, in Figure 13, the longitudinal view of the reinforcement diagram of shear wall lift core for different section is shown. And in Figure 14, a particular section is displayed where the rebar number, rebar diameter and the amount of rebar etc. data are displayed. For the convenience of calculation, the rebar data were kept same along all sections. These data were later used for cost estimation calculation.

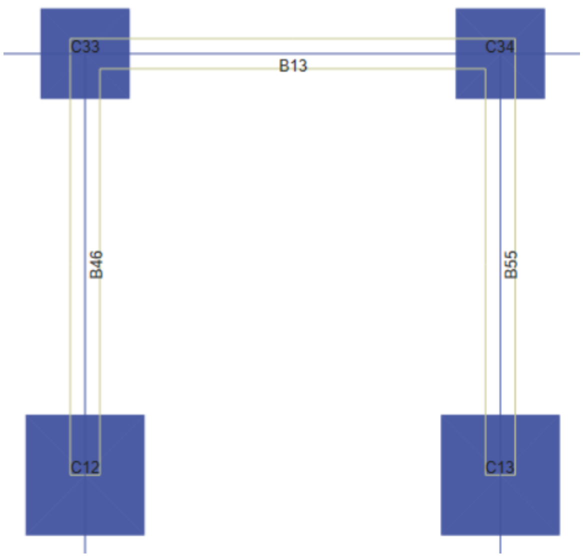


Figure 15: Column and Beam Identification Number for Masonry Wall Lift Core

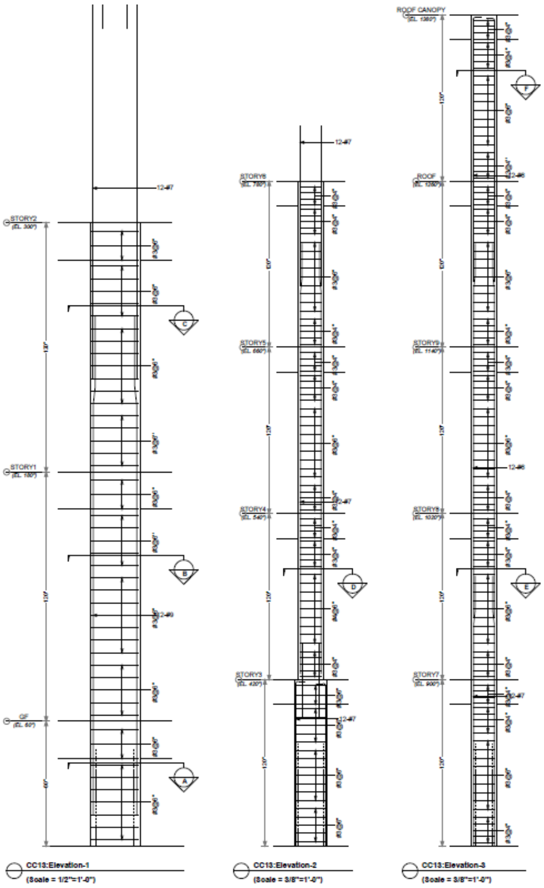


Figure 16: Column 12 & 13 (Longitudinal Rebar)

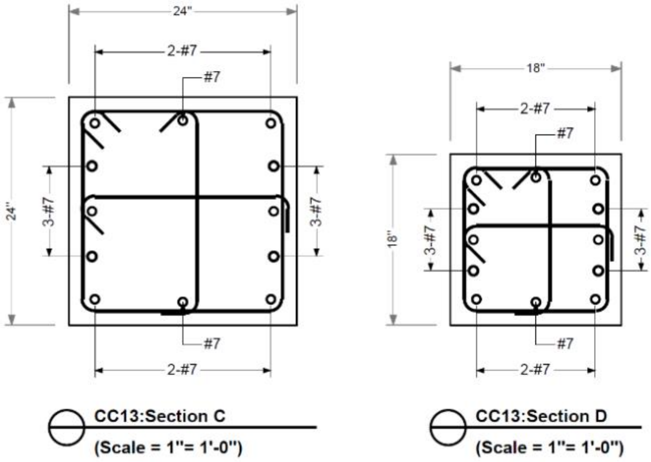


Figure 17: Column 12 & 13 (Rebar Diagram: Section)

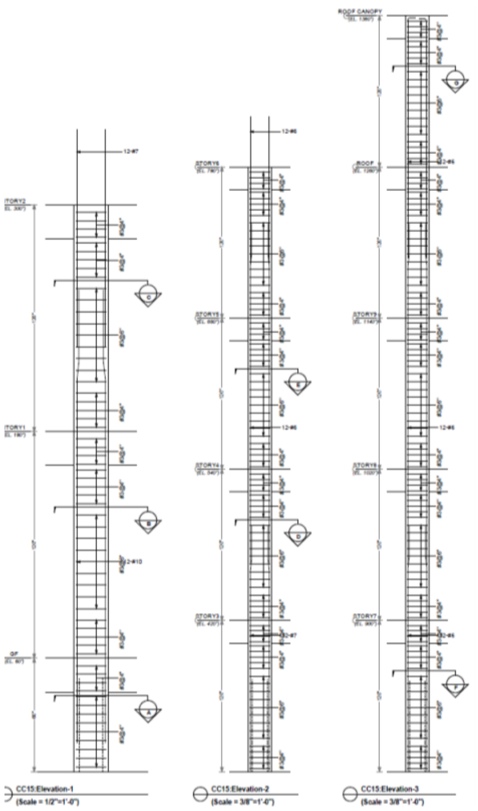


Figure 18: Column 33 & 34 (Longitudinal Rebar)

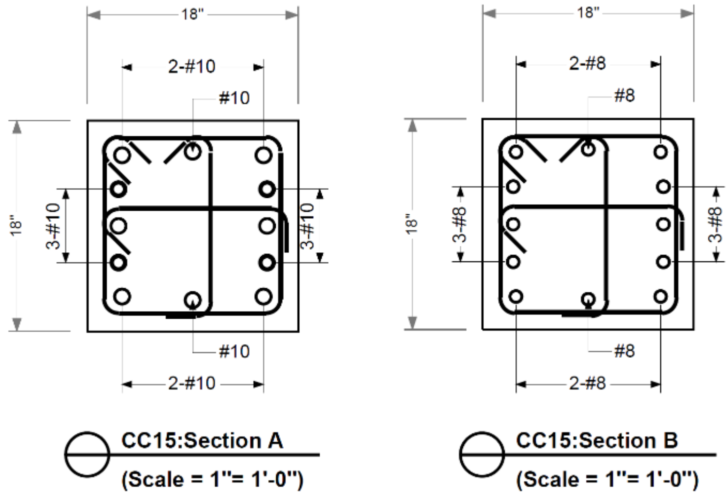


Figure 19: Column 33 & 34 (Rebar Diagram: Section)

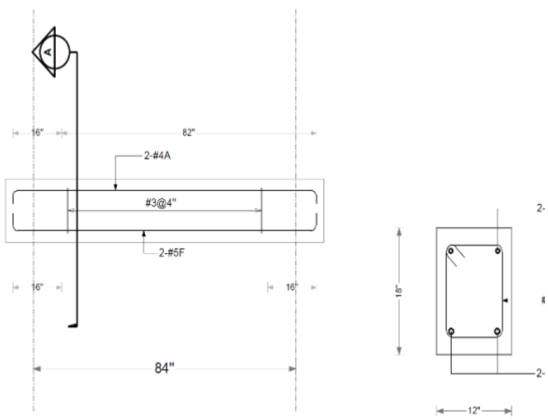


Figure 20: Beam 13 (Rebar Diagram: Section)

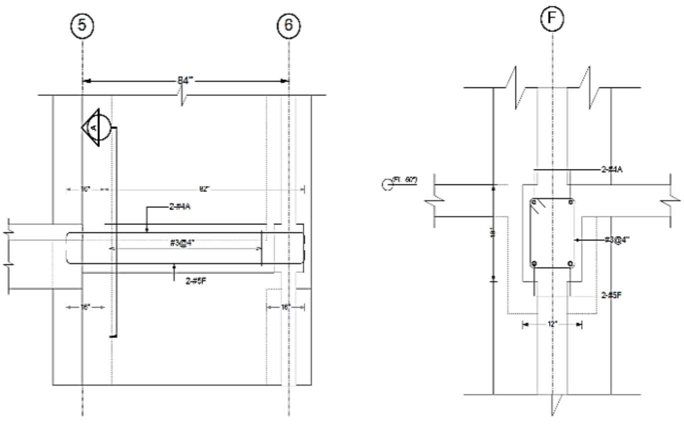


Figure 21: Beam 46 & 55 (Rebar Diagram: Section)

In Figure 15, the identification number for the columns at four corners of the masonry wall is displayed. In Figure 16 and Figure 18, the longitudinal view of the reinforcement diagram of column no 12, 13, 18, and 19 for different sections is shown. And in Figure 17 and Figure 19, section of a column is displayed where the rebar number, rebar diameter, and the amount of rebar etc. data are displayed. For the convenience of calculation, the rebar data were kept the same along all sections.

Again, in Figure 20 and Figure 21, the reinforcement diagram of beam cross section (Beam no 13, 46 and 55) is displayed where the rebar number, rebar diameter and the amount of rebar etc. data are displayed. For the convenience of calculation, the rebar data were kept same along all sections. These data were later used for cost estimation calculation.

After the analysis and design part, ETABS automatically generates the tables related to the analysis result. For this research project, five data tables were determined for both structures- Storey Drift, Base Reactions, Storey Stiffness, Storey Forces, and Storey Shear. These data tables and their comparative analytical graphs are shown in the “Result & Discussion” part.

2.6 Cost Estimation

This section will estimate the cost of constructing the elevator cores for these structures. The costs related to the lift core, such as rebar materials, concrete cast materials, and masonry construction materials, will be the exclusive emphasis of this cost estimate. By isolating these expenses, a more precise estimate may be created to contribute to the overall budget for lift core planning for the project. Tables 7, 8, 9, 10, 11, and 12 show the cost estimation for the materials used to construct lift core.

Some General material cost is mentioned below according to Bangladeshi standard BDT currency-
Per Metric Ton rebar cost = 89,000 BDT
Per bag cement cost = 500 BDT
Per cubic feet of sand cost = 18 BDT
Per cubic feet of sand cost = 200 BDT
Per unit brick cost = 10 BDT
Water cost/1000L = 15 BDT
General Concrete Mix Ratios-
For Mortar, Water: Cement: Sand = 1:2:3
For Plaster, Cement: Sand = 1:4; Water cement ratio= 20%
For M15 Concrete, Cement: Sand: Stone=1:2:4; Water Cement Ratio= 45%

2.6.1 Cost Estimation for Shear Wall Lift Core

Table 7: Cost Estimation for Rebar materials in Shear Wall

Bar Type	Bar Size	Length of Bar (Nominal) (ft)	No of Rebar Required	Rebar Weight (M. Ton)	Rebar Dia (in)	Rebar Volume (ft^3)	Rebar Cost (BDT)
Tie Bar	#3@14" c/c	4172.130	106	0.712	0.375	3.199	63394
Longitudinal Bar (General)	#4@16" c/c (F1, F3) & #4@15" c/c (F2)	5118.000	130	1.598	0.5	6.979	142260
Longitudinal Bar (Corner)	#6@6" c/c	1137.330	29	0.778	0.75	3.489	69282
				Total Rebar Volume & Cost (BDT)		13.668	274936

Table 8: Cost Estimation for Concrete Materials in Shear Wall

Properties	Value	Properties	Value
Wall Height (ft)	115	Cement Vol (ft^3)	170.547
Wall Width (ft)	7	Cement Volume/Bag (ft^3)	1.226
Wall Thickness (ft)	0.5	No Cement Bag Need	140
No of Wall	3	Total Cement Cost (BDT)	70000
Nominal Volume of Wall (ft^3)	1207.500	Sand Vol (ft^3)	341.095
Total Rebar Volume (ft^3)	13.668	Sand Cost (BDT)	6140
Gross Volume of Concrete(ft^3)	1193.832	Stone Volume (ft^3)	682.190
Per Bag Cement Cost (BDT)	500	Total Stone Cost (BDT)	136438
Per cft Sand Cost (BDT)	18	Water Vol (Lit)	2173.211
Stone Cost per Cft (BDT)	200	Water Cost (BDT)	33
Water Cost/1000L (BDT)	15	Total Cost for Concrete (BDT)	212610

Total Cost for Lift core construction by using shear wall = Total Rebar Cost (BDT) + Total Cost for Concrete (BDT)

= (274936 + 212610) BDT

= 4,87,546 BDT

2.6.2 Cost Estimation for Masonry Wall-Column Lift Core

Table 9: Cost Estimation for Brick in Masonry Wall-Column Lift Core

Wall ID	No of wall	Wall length (ft)	Wall Thickness (ft)	Wall Height (ft)	Wall Volume/ Wall (ft^3)	Brick Volume (ft^3)	Morter Clearance (ft^3)	Abs. Volume/ Wall (ft^3)	No of Brick Required	Total cost
W1	11	7	0.46	10	32.08	0.08	7	25.08	301	33110
W2	11	7	0.46	10	32.08	0.08	7	25.08	301	33110
W3	11	7	0.46	10	32.08	0.08	7	25.08	301	33110
W4	11	7	0.46	10	18.08	0.08	7	11.08	133	14630
W5	1	7	0.46	5	16.04	0.08	4	12.04	145	1450
W6	1	7	0.46	5	16.04	0.08	4	12.04	145	1450
W7	1	7	0.46	5	16.04	0.08	4	12.04	145	1450
W8	1	7	0.46	5	16.04	0.08	4	12.04	145	1450
							Total Cost of Brick (BDT)			119760

Table 10: Cost Estimation for Mortar and Plaster in Masonry Wall-Column Lift Core

Properties	**Value**	**Properties**	**Value (Mortar)**	**Value (Plaster)**
Wall Height (ft)	115.00	Cement Vol (ft^3)	101.20	25.87
Wall Width (ft)	7.00	Cement Volume/Bag (ft^3)	1.23	1.23
Wall Thickness (ft)	0.50	No Cement Bag Need	88.00	22.00
No of Wall	4.00	Total Cement Cost (BDT)	44000.00	11000.00
Plaster Thickness	0.42	Sand Vol (ft^3)	162.00	106.78
Total Volume of Morter (ft^3)	308.00	sand Cost (BDT)	2916.00	1947.00
Total Volume of Plaster (ft^3)	129.36	Water Cement Ratio (%)	0.20	0.20
Per Bag Cement Cost (BDT)	500.00	Water Vol (Lit)	2605.15	1200.97
Per cft Sand Cost (BDT)	18.00	Water Cost (BDT)	40.00	18.00
Water Cost/1000L (BDT)	15.00	Total Cost (BDT)	47036.00	12966.00
		Total Cost for Mortar & Plaster (BDT)	60002	

Table 11: Cost Estimation for Rebar Materials in Columns and Beams in Lift Core

Beam/ Column	**Rebar Size 1**	**Num of Rebar**	**Bar Weight (lb)**	**Rebar Size 2**	**Num of Rebar**	**Bar Weight (lb)**	**Total Longitudinal Bar Cost (BDT)**	**Tie Bar**	**No of Rebar**	**Bar Weight (lb)**	**Total Tie Bar Cost**
C12	12#9	19	2545.24	12#6	122	7219.81	394212	#3@4"	164	2429.56	98081
C13	12#9			12#6				#3@4"			
C33	12#9			12#6				#3@4"			
C34	12#9			12#6				#3@4"			
B46	Top: 2#4	52	1409.57	Bottom: 2#5	52	2136.90	143170	#3@3"	90	1333.30	53825
B13	Top: 2#4			Bottom: 2#5				#3@3"			
GB46	Top: 2#4			Bottom: 2#5				#3@3"			
GB13	Top: 2#4			Bottom: 2#5				#3@3"			
Total Cost for Rebar Materials = 689288 BDT											

Table 12: Cost Estimation for Concrete Materials in Masonry Wall-Column Lift Core

Beam/ Column	Column Volume (ft^3)	Cement Vol (ft^3)	No of Cement Bag Required	Total Cement Cost	Sand Vol (ft^3)	Sand Cost	Stone Vol (ft^3)	Stone Cost	Water Vol (Lit)	Water Cost
C12	455.07	65.01	53.02	82588	130.02	2340	260.04	52008	828.39	12
C13	455.07	65.01	53.02		130.02	2340	260.04	52008	828.39	12
C33	253.82	36.26	29.57		72.52	1305	145.04	29008	462.04	7
C34	253.82	36.26	29.57		72.52	1305	145.04	29008	462.04	7
B46	41.92	5.99	4.88	23787	11.98	216	23.96	4791	76.31	1

B13	20.95	2.99	2.44	5.99	108	11.97	2394	38.14	1
GB46	230.32	32.90	26.83	65.81	1185	131.61	26323	419.28	6
GB13	115.15	16.45	13.42	32.90	592	65.80	13160	209.62	3
		Total Bag of Cement	213.00	Total Sand Cost	9391	Total Stone Cost	208701	Total Water Cost	50
Total Cost in Concrete (Column and Beam) = 324517 BDT									

Total cost for lift core construction by masonry wall-column = (119760+60002+689288+324517) BDT
= 11,93,567 BD

3. Results and Discussion

3.1 Maximum Storey Drift Due to Seismic Action

Table 13: Storey Drift

Story	**Drift X (masonry)**	**Drift X (shear wall)**	**Drift y (masonry)**	**Drift y (shear wall)**
Roof Canopy	0.000973	0.001951	0.000828	0.001734
Roof	0.000919	0.00155	0.000958	0.001871
9th Floor	0.001114	0.00171	0.001176	0.002397
8th Floor	0.0014	0.001962	0.001442	0.003036
7th Floor	0.001626	0.002205	0.001668	0.003709
6th Floor	0.00179	0.002426	0.001837	0.004355
5th Floor	0.001893	0.002622	0.001989	0.004918
4th Floor	0.001939	0.002767	0.002134	0.005315
3rd Floor	0.001924	0.002835	0.002134	0.0054
2nd Floor	0.00184	0.002756	0.001948	0.004905
1st Floor	0.001584	0.002063	0.001499	0.00325
GF	0.000555	0.000605	0.000621	0.000983

The variation in storey drift along X-axis (longer direction) is displayed in Figure 22 and Table 13. Again, the variation in storey drift along Y-axis (shorter direction) is displayed in Figure 23 and Table 13. It is visible from the figure that, drift is higher for masonry wall-column cases along X-axis (longer direction) and Y-axis (shorter direction).

Compared to shear walls alone, masonry walls with columns at the corners create a more rigid and stiff structural framework. The columns at the corners distribute lateral loads throughout the structure evenly. Because there are columns at each of the building's four corners, the lateral pressures are dispersed more equally throughout its height. This distribution helps reduce the horizontal displacement (or story drift) between different building parts during lateral loading events. Shear walls, particularly when utilized alone in a lift core, can have greater flexibility or deformability than masonry walls and corner columns. his flexibility might lead to greater story drift under lateral loads.

Drift is observed to be increased from the 3rd to 4th floor and then decreased gradually up to the roof; then again increases till the roof canopy.

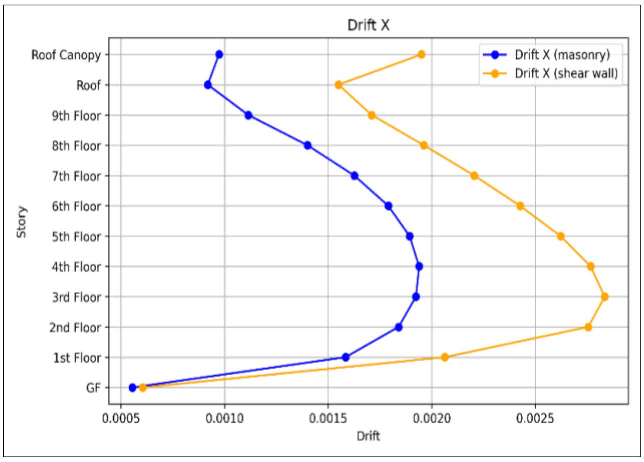


Figure 22: Variation in Storey Drift for E_x

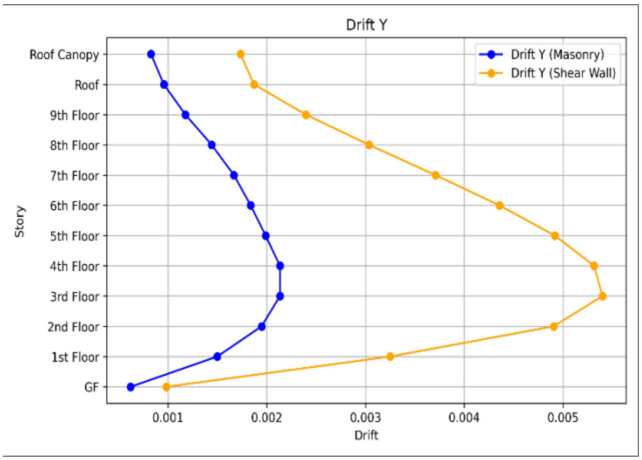


Figure 23: Variation in Storey Drift for E_Y

3.2 Maximum Stiffness Due to Seismic Action

Table 14: Storey Stiffness

Story	Stiff X (masonry) (kip/in)	Stiff X (shear wall) (kip/in)	Stiff y (masonry) (kip/in)	Stiff y (shear wall) (kip/in)
Roof Canopy	120.663	42.792	102.502	46.188
Roof	1354.185	571.078	1148.738	572.789
9th Floor	2040.838	894.205	1846.343	867.849
8th Floor	2331.142	1073.224	2197.265	986.784
7th Floor	2506.818	1182.308	2384.324	1037.354
6th Floor	2658.085	1261.724	2510.213	1066.420
5th Floor	2797.627	1336.421	2631.395	1095.309
4th Floor	2945.882	1431.505	2797.897	1141.642
3rd Floor	3145.713	1564.523	3094.106	1236.595
2nd Floor	3482.113	1819.470	3663.644	1470.922
1st Floor	4329.146	2699.378	5159.638	2364.337
GF	23163.981	18196.532	27057.123	16801.853

The variation in storey stiffness with respect to storey along X-axis is displayed in Figure 24 and Table 14. And the variation in storey stiffness with respect to storey along Y-axis is displayed in Figure 25 and Table 14. Stiffness seemed to be greater for the masonry wall-column lift core structure compared to the structure having a shear wall lift core in both longer and shorter directions. However, there's not a huge difference in stiffness along both axes for both types of structural systems.

The lift core made of masonry walls and corner columns has greater structural stiffness and rigidity than a lift core made of shear walls. The improved load path aids in evenly distributing forces and lowering localized stresses, hence increasing overall stiffness. Shear walls, on the other hand, may have more localized load patterns, which could result in higher flexibility and deformation.

The stiffness seems to have higher values at the ground floor and gradually decreases with the increase in storey height.

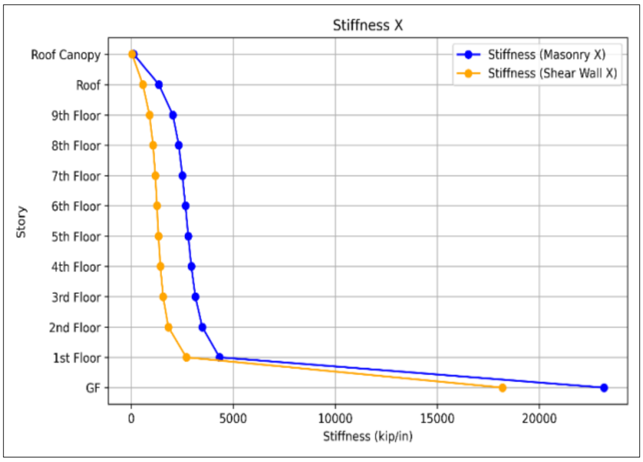


Figure 24: Variation in Storey Stiffness for E_x

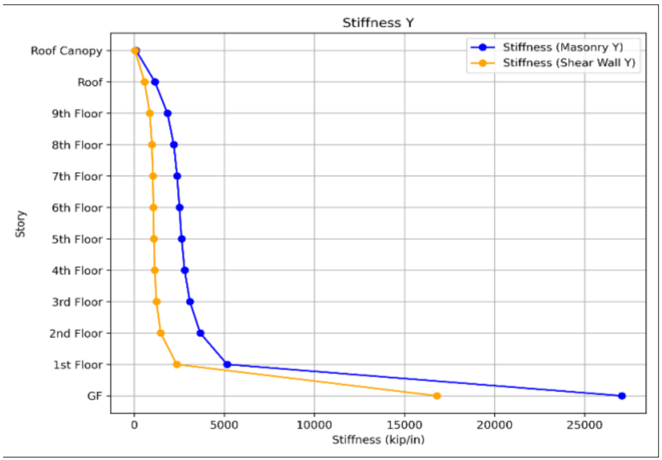


Figure 25: Variation in Storey Stiffness for E_Y

3.3 Maximum Storey Shear Due to Seismic Action

Table 15: Storey Shear

Story	Shear X (masonry) (kip)	Shear X (Shear Wall) (kip/in)	Shear y (masonry) (kip)	Shear y (Shear Wall) (kip/in)
Roof Canopy	11.467	6.526	10.687	5.794
Roof	129.419	86.635	120.616	76.918
9th Floor	251.12	163.767	234.039	145.4
8th Floor	348.499	225.515	324.795	200.223
7th Floor	424.314	273.59	395.452	242.906
6th Floor	481.259	309.699	448.524	274.965
5th Floor	522.031	335.552	486.522	297.918
4th Floor	549.324	352.858	511.959	313.284
3rd Floor	565.873	363.328	527.383	322.579
2nd Floor	574.339	368.669	535.273	327.322
1st Floor	577.387	370.592	538.113	329.029
GF	577.695	370.813	538.401	329.225

The variation in storey shear with respect to storey along X-axis is displayed in Figure 26 and Table 15. And the variation in storey shear with respect to storey along Y-axis is displayed in Figure 27 and Table 15. It is portrayed from the figure that; the storey shear is higher for the structure having masonry wall lift core with corner columns compared to the structure having a shear wall lift core in both longer and shorter directions.

A lift core with masonry walls and corner columns may have higher story shear, but it provides superior strength and stability under lateral pressures. But if project-specific factors taken into consideration, the structure with shear walls can be considered better in terms of minimizing story shear. Shear walls are often designed to transfer lateral stresses more uniformly throughout the structure, resulting in less overall story shear than a system based on masonry walls and corner columns.

The shear in both cases gradually decreased with the increase in the height of the building.

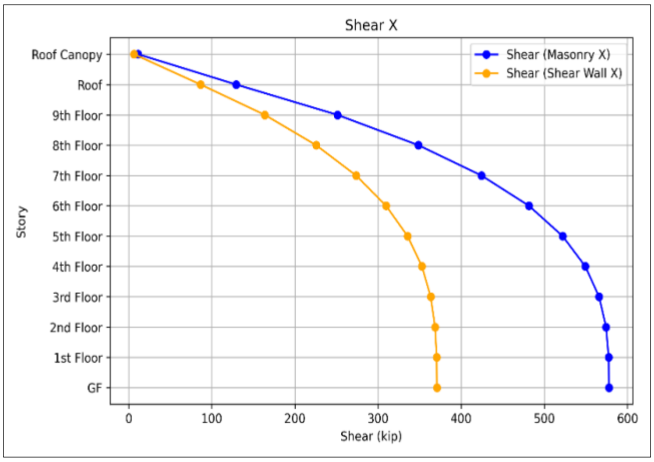


Figure 26: Variation in Story Shear for E_x

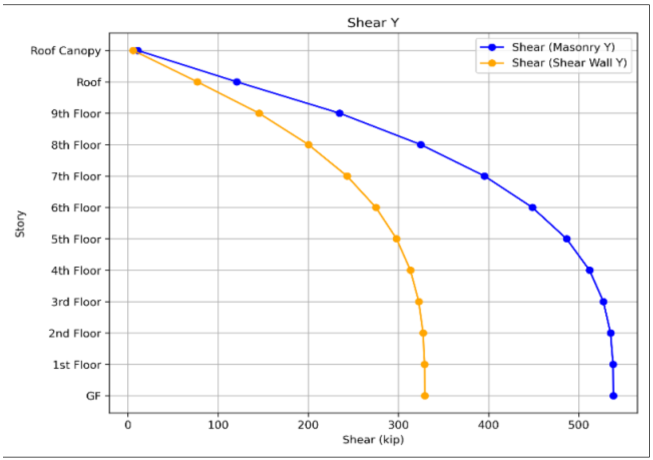


Figure 27: Variation in Story Shear for E_Y

3.4 Maximum Overturning Moment Due to Seismic Action

Table 16: Overturning Moment

Story	O.M X (masonry)	O.M X (shear wall)	O.M Y (masonry)	O.M Y (shear wall)
Roof Canopy	1433.375	815.750	1335.875	724.250
Roof	14883.185	9963.025	13870.840	8845.570
9th Floor	26367.600	17195.535	24574.095	15267.000
8th Floor	33107.405	21423.925	30855.525	19021.185
7th Floor	36066.690	23255.150	33613.420	20647.010
6th Floor	36094.425	23227.425	33639.300	20622.375
5th Floor	33932.015	21810.880	31623.930	19364.670
4th Floor	30212.820	19407.190	28157.745	17230.620
3rd Floor	25464.285	16349.760	23732.235	14516.055
2nd Floor	20101.865	12903.415	18734.555	11456.270
1st Floor	14434.675	9264.800	13452.825	8225.725
GF	8665.425	5562.195	8076.015	4938.375

The variation in overturning moment with respect to storey along X-axis is displayed in Figure 28 and Table 16. And the variation in overturning moment with respect to storey along Y-axis is displayed in Figure 29 and Table 16. It is portrayed from the figure that; the overturning moment is lower for the structure having a shear wall lift core compared to the masonry wall lift core with corner columns in both longer and shorter directions.

A lift core construct with shear walls has several advantages, including lesser overturning moments, more effective lateral force distribution, and potentially cheaper construction costs and complexity. In the design of buildings, lower overturning moments are desirable as they indicate lower structural stress, improve overall stability, and provide an economical solution. However, compared to shear walls, which are usually dispersed over broader regions, Masonry walls with corner columns offer a more concentrated resistance to lateral stresses. The leverage effect of lateral loads might cause increased overturning moments as a result of this concentrated resistance at the corners.

The overturning moment is observed to be increased till the 6th to 7th floor of the building and then decreased gradually giving parabolic shape to the graph.

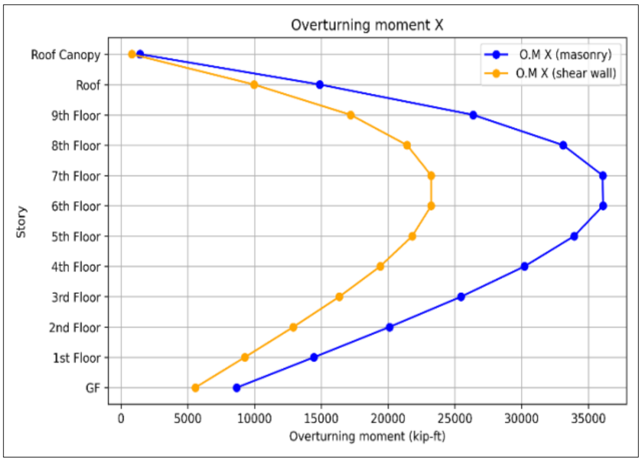


Figure 28: Variation in Overturning Moment for E_x

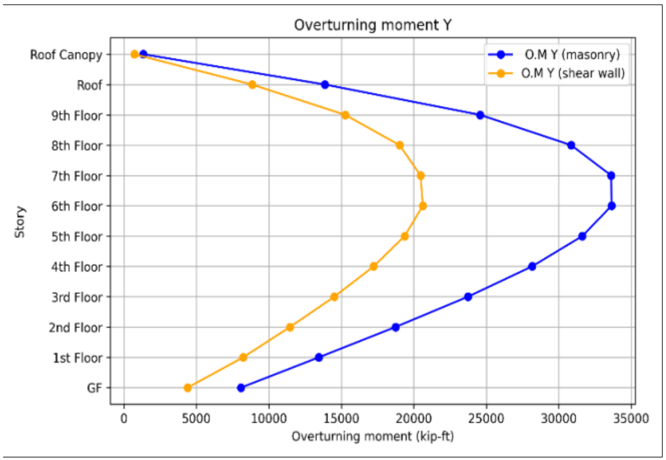


Figure 29: Variation in Overturning Moment for E_Y

3.5 Cost Estimation Result

From sections 2.6.1 and 2.6.2, the total cost of materials for Shear wall lift core was around 4,87,546 BDT (Bangladeshi Taka). And the total cost of materials for masonry-wall column lift core was around 11,93,567 BDT (Bangladeshi Taka). From the estimation its clear that the construction cost of masonry-wall column lift core is significantly higher than shall wall lift core.

4. Conclusions

Based on the research findings, it can be concluded that -
The Structure having a shear wall lift core shows higher drift, slightly lower Story stiffness, lower storey shear, and lower overturning moment compared to the structure having masonry wall lift core with corner columns. However, a lift core construct with shear wall is significantly cost effective also compared to masonry wall-column system. Here, the main three factors that exhibit the seismic performance are- drift, stiffness, and overturning moment. Although masonry wall-column lift core structure has lower drift, it has a higher overturning moment value. Lower storey drift is always preferable for structure. However, In the design of buildings, lower overturning moments are desirable as they indicate lower structural stress, improve overall stability, and provide an economical solution. And in terms of stiffness, neither of the structures showed huge advantages over the other. Because of its lower cost, lower story shear, and less overturning moment, the lift core with shear wall can be regarded as superior overall. The shear wall lift core is a better option for specifically high-rise construction projects due to its cost-effectiveness and acceptable performance qualities, even though it could show somewhat less stiffness and drift than the lift core with masonry walls and corner columns.

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Lathes' Machine Selection Base on Operational Sensitivity and Costing

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Abstract
The need to estimate the cost of operating a machine tool for the purpose of pricing a job or billing a customer is of great importance. This would establish a good relationship between customers and operators. The cost depends on the sensitivity of the machine tool. In determining the sensitivity of lathes, parameters considered were the finishing time of operation in relation to the machining parameters which were feed, capacity and speed at a unit depth of cut. The component design parameters were metal volume removed, complexity and the skill level involved. Costing was done based on literature and the current prime cost of running and operating the machine shop. The developed numerical model has a coefficient of determination R2 of 0.962 specifying a high degree of agreement for experimental and theoretical data. The results showed that lathe machines with smaller capacity have lower operational sensitivity with more cost effectiveness where as higher capacity, numerical control and CNC lathe machines had higher sensitivity but less cost effective.

Keywords: Sensitivity, Model, Finishing Time, Cost Effectiveness, Capacity

1. Introduction

Costing of machine tool operation is of great importance for the purpose of pricing a job or billing a customer. The cost of operation depends on the sensitivity of the machine tool. A product can be produced through various manufacturing processes. The choice of a production process will however depend on specific parameters and consideration (Bruce, 2002). The operation to be carried out on a work piece determines the tool to be used. The advancement of tool usage led to the invention of machine tool (Bradley, 1972). Machine tools are power-driven devices designed to produce a geometrical surface by cutting away metal through operations such as turning, shaping, milling (Kareem, 2004; Kareem *et. al.,* 2010). Machine tools are basic mechanical machinery used to produce or repair other machine parts which includes lathe, milling and drilling machine.

The global market is filled today with the conventional type, numerical control (NC) and computer numerical control (CNC) machine tools (Kareem *et al*, 2010), in consideration for determining machining sensitivity, categories of machine are selected towards estimating the most efficient and economic one required for production through mathematical modeling with respect to meeting the five firm objectives as stated by Cyert and March (1963), Kareem (2005), Kareem (2006) and Palik (2006). These are profit, production, stock levels, sales and market share considerations. This work will greatly enhance selection of appropriate machine tool (lathe) that will be used in the production of mechanical components, and optimization of profitability from the utilization of the machine tool in the industry. The costing would establish a good relationship between customers and operators.

2. Research Methodology

Various factors affecting operational sensitivity of lathe machine tool were identified. These factors were the volume of the metal removed, complexity of operation, cutting speed, depth of cut, feed rate, accuracy of cut, machine capacity (stock) and operator skill level at which the machine was operated.

Theoretical relationship among the identified operational factors was mathematically formulated and expressed in equation 1 by Boothroyd and Knight, (1989).

$$t_{total} = t_{load} + \frac{V_{vol}}{f_{mach} fdV} + \frac{V_{vol} V^{(1-n)n} t_{ct}}{fdK^{1/n}} \quad (1)$$

Where, t_{total} is true machining time, t_{load}, time for loading and unloading the part to and from machine tool, V_{vol}, Volume removed, f_{mach}, fraction of the time spent in removing metal, t_{ct}, tool changing time, f, feed rate (mm/rev.), d, depth of cut (mm), V, Velocity (m/min) also know as cutting speed, n, an index closely related to the cutting tool materials 0.1-0.6 and K, a constant for the time required to produce N parts. In order to improve operational sensitivity of the system, the formulation was extended to include managerial parameters such as complexity of operation, skill level available, accuracy desired and capacity of machine. The resulted robust model was used in determining the true operation time of job requisition. A new and simple numerical approach, based on multiple regressions by Gujarati (2007) was adopted in obtaining a model that holistically integrated the identified sensitivity driven factors. With true machining time, t_{total} as a function of skill, S, volume removed, V, feed, F, spindle speed, N, stock length, K, complexity, C, and accuracy, A, are presented in equation 2 and 3 as given by Kareem and Ejiko, (2013).

$$t_{total} = f(S, V, F, N, K, C, A) \quad (2)$$

The regression model was formulated from

$$t_{total} = aS + bV + cF + dN + eK + fC + gA + h \quad (3)$$

where a, b, c, d, e, f, g and h are coefficients/constant of regression model.

In order to establish the efficacy of multiple regression relationship, experimental study was done by carrying out designated operations on lathe models of Conventional type, in the Machine Workshop of Mechanical Engineering Department, the Federal Polytechnic Ado-Ekiti. The designated operations carried out included turning, drilling, threading, on which different levels of operators' skill, volume of material removal, complexity of job, speeds and feeds of operation were utilized. From the data generated through experimental procedure, analysis was carried out on Multiple Regression model using Statistical Package for Social Sciences (SPSS 15.0) software and the true machining time was determined.

2.1 Costing of Machine Tool

In costing the lathe model of machine tool, cost implication that involves the machining charge for recovering the capital cost, labour cost and tooling cost was considered has been treated by Dieter (1991). Formulae for the manufacturing cost and labour cost were given which include;

$$M_t = \frac{C_i}{120000 f_0 n_s}\left[\frac{1}{Y} + \left(f_i + f_m\right)\right] \quad (4)$$

$M_t =$ Manufacturing cost per minute

$C_i =$ Initial purchase price

$f_i =$ Fraction of interest rate to the purchase price

$f_m =$ Fraction of annual cost of power, lighting, heating, training and so on

Y = Machine age

$f_0 =$ Fraction of machine active hour

n_s = Number of days factor for process-oriented jobs

$$M_w = \frac{C_a}{120000}(1 + f_s)r_w \qquad (5)$$

M_w = Labour rate per minute

$C_a =$ Worker's annual wage

f_s = Fraction of insurance/pension cost of wages

r_w = Factor of payment for others not necessarily the operator (Dieter, 1991)

These formulas with other data gathered from Thomas *et al.* (2000) as shown in Table 1 are useful in estimating the machine rate per minute. The data collected from Thomas *et al*, 2000, machine tool industries and the internet on CNC lathe in Wikipedia, (2007) and Microkinetics, (2009) as reflected in Tables 1 and 2 were used to estimate the operation charge per minute. With contracting differences found in the utilization of the varying lathe models, there is the need to determine the operational sensitivity for each class of lathe and the economic implication, Hence the need to develop operational sensitivity model in the selection of the most cost-effective lathe.

Table 1: Fractional factors in estimating machine hour rate

factor	Conventional	NC	CNC
f_i	0.15	0.15	0.15
f_m	0.4	0.45	0.18
f_o	0.5	0.75	0.75
n_s	2	2	2
f_s	0.1	0.1	0.1
r_w	1.2	1.2	1.2

Source: Thomas et al. 2000

Table 2: Parameters for Estimating Machining Cost Per Minute

Sub-component charge	M300	M350	M500	N/C 3650	CNC 1236
Fuel consume/hour	100	150	200	270	100
For 8 hour of 250 work days	₦ 200,000	300,000	400,000	540,000	200,000
Fm = annual cost of power/etc fraction to cost	0.4	0.5	0.5	0.45	0.18
F: = fraction of interest rate if borrow to purchase	0.15	0.15	0.15	0.15	0.15
C_I = purchase price	500,000	600,000	800,000	1200,000	1,119,300
Machine Age	13	17	7	1	1
M_t = manufacturing cost/min	2.61	3.54	5.29	10.67	8.27
F_o= machine active hr fraction	0.5	0.5	0.5	0.75	0.75
N_s = days factor (process-oriented).	2	2	2	2	2
C_a = workers annual wage	360,000	360,000	360,000	600,000	600,000
F_s = insurance/pension fraction	0.1 (10%)	0.1	0.1	0.1	0.1
R_w = inflated ration for other pay (labour intensive)	1.2	1.2	1.2	1.2	1.2
M_w = labour charge/min	3.96	3.96	3.96	6.60	6.6
C_p = turning process cost	6.57	7.5	9.25	17.27	14.87

Source: Thomas et al., 2000: and www.Microkinetcs.com/lathe 1236

3. Results and Discussion

Linear multiple regression model parameters were estimated from the data obtained through the experiment conducted on operational sensitivity for the three models of the conventional lathe machine (M300, M350 and M500), in the mechanical workshop of the Federal Polytechnic Ado-Ekiti, using SPSS 15.0 (for window) computer package. The parameters for the independent variable namely: volume, federate, speed, stock, complexity, accuracy and skill for the three lathe models are presented in equation 6 which is the Generalized model that considered the whole variables in the experimental data and the analysis was done using linear multiple regression method. A model of time as a function of the other variables was determined as:

$$T = 13.356S - 0.154A + 2.703C - 0.011K - 0.083N + 151.25f + 1.72V - 20.389. \quad (6)$$

Where, S = Skill level of operator, A = Accuracy of component being machined, C = Complexity of operation, K = Stock length, N = Speed in revolution per minute, f = Feed rate in mm/rev and V = Volume of metal removed. The machine age, swing and power variables were excluded from the model predictors in Table 2 because their variables were insignificant in determination of the operating time (T). The Probability value (Pval) for the general model is 0.001(that is $P_{val} \leq 0.005$) which, shows that there are significant differences among the predictor variables with respect to completion time, correlation factor of 0.962 shows a high degree of the result linearity (Oladebeye and Ejiko, 2007; Ejiko and Kareem, 2012). This general model clearly shows that the skill, complexity, feed and volume have much impact on the machining time while accuracy, stock and speed slightly affect the estimated time. This model clearly stands out from others due to the inclusion of vital modes of operation functions and its machine capacity. The relationship between volume and time of cut is presented in Fig 1, for observed (T obsvd) and theoretical time (T gen). The figure shows that for small volume (0.88cm^3 to 5cm^3) of metal removed involving smaller component with complex operation takes more time in completing the job, as the volume increases from 5cm^3 the time of cut then to be proportionate. The theoretical model clearly agrees with the observed relationship between the volume removed and time of cut, this highlights the acceptability of the generalized model.

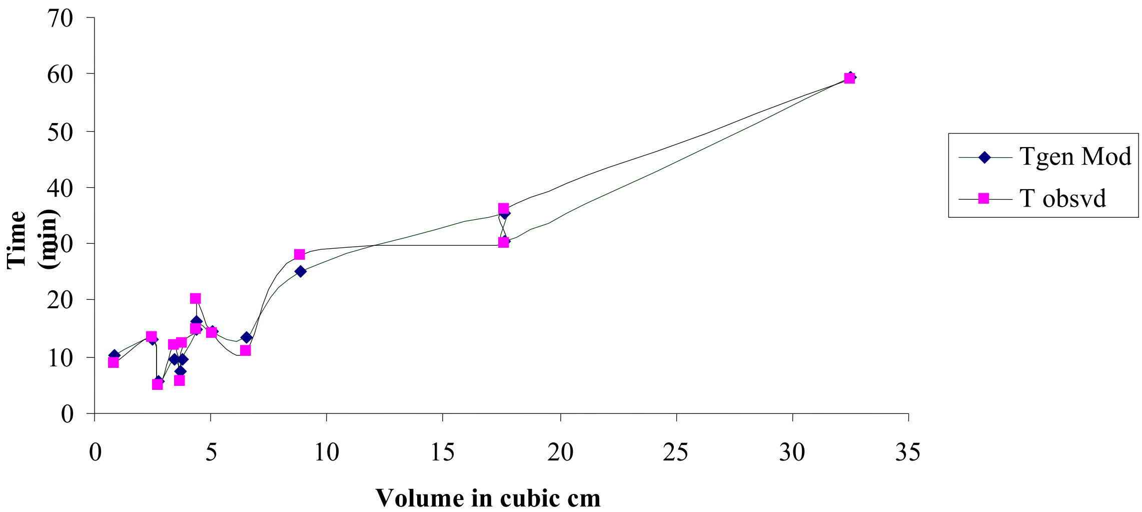

Figure 1: Relationship between Volume and Time of cut for Observed and Generalized Model

In validating the model's data were obtained based on customer's request. The requests involved the production of 15 test piece components having 0.007mm accuracy and metal volume removed per piece is 28.997cm^3 for a period of 5 hours; this implies 20 minutes per component. The model was tested to determine the acceptance or rejection of the job. Considering minimum condition of beginners' skill, lowest turning speed and minimum feed rate, the following result was generated and tabulated in Table 3. The result clearly shows that the M300 lathe is not suitable for the job because the minimum time required to complete the job is higher than the customer time (20 min). M350 met the desired customer's target at a speed above 155 rev/min while M500 can be used with a speed slightly above 115 rev/min. Whereas in a case where all the customer's target are met by all Lathe models, The cost per hour of operations on job using these lathe machines was compared and the best costeffectiveLathe, was chosen for the job utilization.Figs. 2a and 2b show the relationship between speed and time of cut using the generalize model, while Fig. 2a shows the relationship for M300, M350 and M500, Fig. 2b establishes the relationship for M500, NC and CNC lathe involving the machining of a component based on customer's request. The figures show that increase in spindle speed of the lathe machine tool will favour the reduction of machining time, and this varies for varying lathe models. The speed of 75rev/min gives the machining time of 32, 28, 25, 21 an16min for M300, M350, M500, NC and CNC respectively, while at 175rev/min the machining time reduces to 23, 19, 16, 15 and 8min, the implication is that operational sensitivity increases with respect to lathe model capacity and speed.

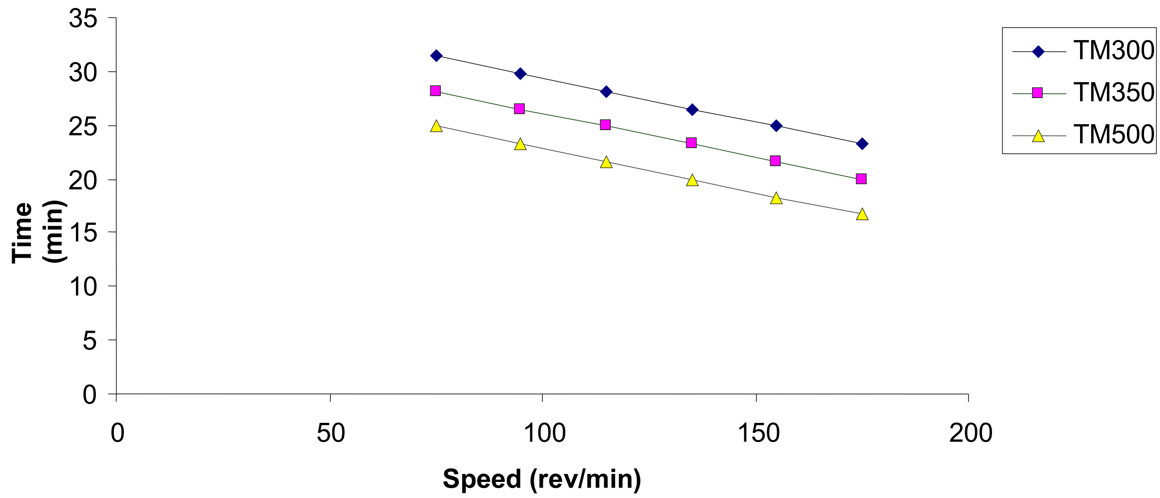

Figure 2a: Relationship between Times of cut and Speed using Generalized Model for Purely Conventional machines

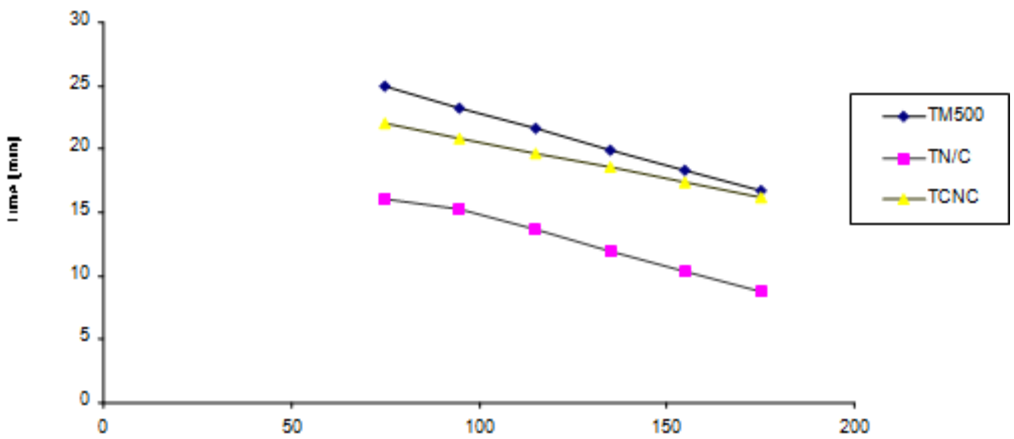

Figure 2b: Relationship between Times of cut and Speed using Generalized Model for Conventional, NC and CNC machines

Table 3: Varying Speed against Time using Generated Model

Job component operation based on varying speed S/№	Speed(rev/min)	Time(min)		
		M300	M350	M500
1	75	31.5	28.2	24.9
2	95	29.8	26.5	23.2
3	115	28.2	24.9	21.6
4	135	26.5	23.2	19.9
5	155	24.9	21.5	18.8
6	175	23.2	19.2	16.7

Cost implication graph in Fig 3 clearly shows that the cost of operating machine at a lower speed is higher, which implies uneconomical operational sensitivity. At higher range of speed for turning mild steel the conventional and numerical control machines are more cost-effective than the computer numerical control lathe machines. The figure shows that at lower speed the cost of operation is usually higher, at 75rev/min the cost in naira of M350, M500, NC and CNC lathe model, are 330, 280, 230 and 220, respectively while, at 175rev/min the cost was estimated to be 149, 153, 150 and 241in naira. As the speed increases the cost of operation tend to reduce. The cost of operation in naira at higher speed for M500, NC and CNC tend to become equal.

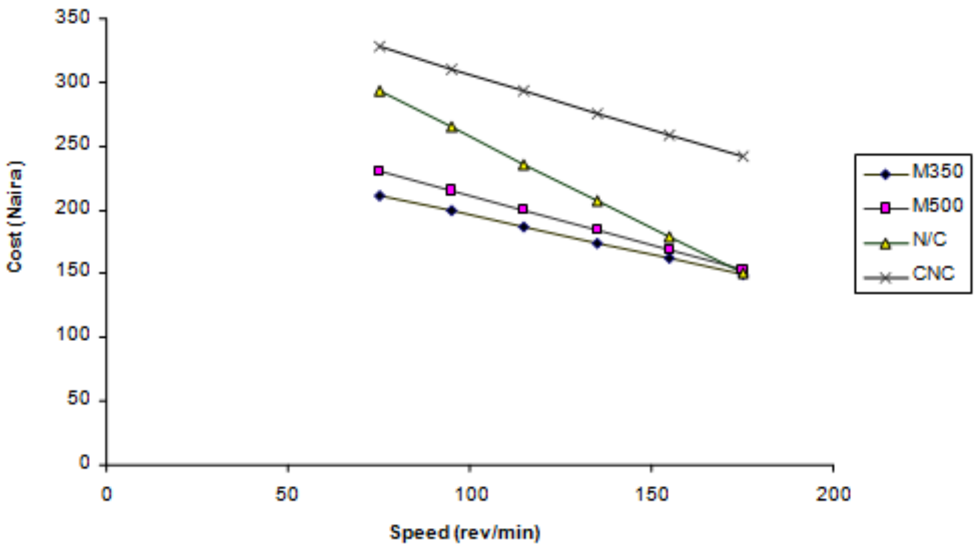

Figure 3: Relationship between manufacturing cost and speed of Operation for conventional NC and CNC machines

4. Conclusions and Recommendations

This paper expressed the operational sensitivity model for selection of appropriate Lathe machine in the production of mild steel components. The numerical models based on multiple regressions were developed from the experimental data obtained from machining operations of some specified jobs. The Lathes in machine shop of Mechanical Engineering Department of The Federal Polytechnic Ado Ekiti was used as a case study. The resulting models possessed high correlation factors which show high levels of agreement among the observed and theoretical values of variables (Skill, Feed, Accuracy, Stock, Volume removed, Speed and Complexity) relationship, as input, with respect to the time of completion, as output. The developed model has successfully estimated the machining time for varying job requests in the machine tools industries.

This paper establishes a selective measure in the choice of economical machine tools for operations. In summary, the result obtained shows that lathe model, with smaller capacity possesses lower operational sensitivity with respect to time, whereas models with higher capacity, numerical control and CNC machines attracted higher operational sensitivity and cost.

The implementation of the model has enhanced effective utilization of available resources including lathe machines, from which good interrelationship between customers'requests and operators' available time was established. This has resulted in effective operation charges in the machine shops.

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Status of Solid Waste Management in Kaduna and Bauchi of Nigeria

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Abstract
Reliable database is a requirement to support policies and decision-making for efficient solid waste management. The aim of this study is to establish the status of solid waste management by assessing solid waste generation and composition, characterization, collection methods and the effectiveness of existing practices and strategies in Kaduna and Bauchi State. A structured questionnaire was employed to gather data on waste management practices and awareness, willingness to sort at source and to pay for proper waste management. Solid waste generation, composition and characterization including bulk density, moisture content, were established by site and laboratory analysis. 100 houses per city were surveyed in Bauchi and Kaduna with the population of 669 and 675 respectively. 0.25kg/capita and 0.35 kg/capita were recorded in Bauchi and Kaduna respectively. The waste is predominantly food waste for both Bauchi (47.1%) and Kaduna (53.5%) and recyclable fractions of 29.4% and 26% respectively. Bulk density was established at 412.3 kg/m3 and 407.8 kg/m3 for Kaduna and Bauchi with moisture content at 40% and 60%. Calorific values and volatile solids obtained were 10.3MJ/kg and 46% for Kaduna and 18MJ/kg and 50% for Bauchi. 2% of the households in Kaduna partially sort waste and 13% and 27% of the households in Bauchi and Kaduna reuse the plastic bottles. Meanwhile, 35% and 41% of the residents showed willingness to separate waste at source in Bauchi and Kaduna respectively. Although treatment at household level was nonexistent, 60% of the residents indicated a willingness to treat with adequate technical knowledge. The predominant disposal methods of open dumping and burning pose environmental and health risks, emphasizing the urgent need for improved waste management infrastructure and awareness campaigns. Despite these challenges, the community's willingness to engage in proper waste management practices underscores the potential for positive change through education and implementation of effective waste management.

Keywords: Solid Waste, Solid Waste Management, Nigeria

1. Introduction

1.1 Solid Waste Management

Solid waste management is a multi-faceted process that encompasses waste generation, waste collection, recycling, and treatment to final disposal of unwanted solid material (Allesch & Brunner, 2014). Solid waste management is a critical aspect of environmental sustainability, necessitating comprehensive strategies for minimizing waste generation, promoting recycling, and ensuring proper disposal of residual waste (Mwanza et al., 2018). Effective management of solid waste is crucial for mitigating environmental pollution, conserving resources, and safeguarding public health (Awasthi et al., 2019).

The global volume of solid waste generation has been escalating due to population growth, urbanization, and industrialization, posing significant challenges for waste management systems worldwide (Adedara et al., 2023). In low-income countries, such as Nigeria, the predominant methods of disposal are uncontrolled open dumping and burning with the severe environmental health and safety consequences – climate change, spread of diseases and encouraging urban violence (Mama et al., 2021; Voukkali et al., 2024). Addressing this issue requires integrated approaches that encompass waste reduction, reuse, recycling, and appropriate treatment methods (Babaei et al., 2015).

Promotion of waste minimization and resource recovery is an important aspect of solid waste management. Research highlights the importance of adopting sustainable consumption patterns and encouraging the reuse of materials to reduce the overall burden on waste management infrastructure (Wang et al., 2020). Implementing policies and initiatives that encourage manufacturers to design products with recyclability and durability in mind can contribute to minimizing the generation of waste at the source, thus promoting a circular economy model (Wang et al., 2020).

Furthermore, the adoption of advanced technologies and innovative waste management practices is essential for enhancing the effectiveness and sustainability of waste treatment processes. Recent studies highlight the potential of technologies such as waste-to-energy conversion, anaerobic digestion, and composting in diverting organic waste from landfills and harnessing its energy potential. Integrating these technologies into solid waste management systems can help reduce greenhouse gas emissions, mitigate environmental contamination, and recover valuable resources from waste streams (Young, 2010).

Reliable database is a requirement to support policies and decision-making for efficient solid waste management (Harir et al., 2017). Furthermore, solid waste management requires a diversified approach that encompasses policy interventions, public awareness campaigns, technological innovations, and stakeholder collaboration (Harir et al., 2017).

1.2 Solid waste generation

Solid waste generation and composition are critical components in the development of effective waste management strategies aimed at mitigating environmental pollution and promoting sustainable resource utilization (Pujara et al., 2019). Solid waste generation refers to the solid left over of all processes where materials are used (Lagerkvist & Dahlén, 2012). Solid wastes are generated from extraction of raw materials, manufacture of products and consumption (Abdel-Shafy & Mansour, 2018). Urban areas generate a significant portion of solid waste, with per capita waste generation rates influenced by socio-economic factors, cultural practices, and waste management infrastructure (Louati et al., 2019).

1.3 Solid waste composition

Municipal solid waste physical and chemical composition varies geographically and is influenced by factors such as population demographics, consumer behavior, food habits, standard of living, degree of commercial activities, and seasons (Wang et al., 2020; Kolekar et al., 2016). While organic waste, paper, plastics, and packaging materials remain predominant components of municipal solid waste, the proportion of certain materials, such as electronic waste and single-use plastics has been steadily increasing in recent years (Wang et al., 2020; Kolekar et al., 2016). By conducting detailed compositional analyses, waste management authorities can identify priority materials for recycling, composting, or energy recovery initiatives (Louati et al., 2019). Alabdraba & Al-Qaraghully (2013) summarized ranges of waste composition and characteristics for high, middle and low-income countries as shown in Table 1.

Table 1: Waste composition of high, middle and low income countries

Components	High income	Middle income	Low income
Food waste	7 - 55	20 - 65	40 - 85
Paper and cardboard	15 - 50	15 - 40	1 - 10
Plastics	2 – 20	2 - 13	1 - 11
Leather and rubber	2 - 12	1 - 5	1 - 3
Glass	4 - 10	1 - 10	1 - 10
Metals	3 - 13	1 - 5	1 - 5
Ash and dirt	5 - 20	15 - 40	15 - 50
Moisture (%)	20 - 35	40 - 60	40 - 80
Density (kg/m^3)	120 - 200	170 - 330	250- 500

1.4 Solid Waste Management

Solid waste management encompasses; temporary storage, collection, transportation, treatment and disposal (Muthuraman & Ramaswamy, 2019). Temporary storage facilities can vary from simple waste bins or containers at households and businesses to larger transfer stations or depots where waste is consolidated before further transportation (Kulkarni & Anantharama, 2020). The duration of temporary storage is commonly based on waste generation rates, collection schedules, and the capacity of the storage facility. Typically, waste remains in temporary storage for a few hours to a few days (Nanda & Berruti, 2021).

Solid waste collection is the critical and capital-intensive aspect of solid waste management covering about one-third of the total waste management capital expenditure aimed at efficiently gathering and managing various types of waste generated by residential, commercial, and industrial activities (Sharma & Jain, 2020; Hannan et al., 2020). The types of solid waste collection include curbside, communal collection (Pérez et al., 2020; Pires et al., 2019).

In recent years, advancements in technology, policy frameworks, and community engagement have reshaped approaches to waste treatment and disposal, offering innovative solutions to address environmental concerns and resource conservation (Malinauskaite et al., 2017). Waste to Energy (WtE) is a process in solid waste management where the energy content of waste materials is converted into usable energy forms such as electricity, heat, or fuel (Kumar & Samadder, 2017). This approach aims to address two critical challenges: waste disposal and energy generation. By converting waste into energy, WtE facilities help alleviate the strain on landfills, reduce greenhouse gas emissions, and contribute to the diversification of energy sources (Moya et al., 2017).

Waste to Energy facilities typically employ various technologies such as mass burn incineration, gasification, pyrolysis, and anaerobic digestion to convert solid waste into energy (Kumar & Ankaram, 2019). Examples of such facilities are the SEMASS Resource Recovery Facility in Massachusetts, USA, processes municipal solid waste (MSW) through mass burn incineration to produce electricity and the Edmonton Waste Management Centre in Alberta, Canada, integrates anaerobic digestion technology to process organic waste to produce biogas (methane) and nutrient-rich digestate (Khan et al., 2016; Giraud et al., 2021).

Recycling and Material Recovery play pivotal roles in sustainable solid waste management by diverting valuable materials from landfills, conserving natural resources, and reducing environmental impacts (Scarlat et al., 2019). Materials such as paper, plastics, textile, glass, metals, and organic waste are collected, sorted, and processed to be used as raw materials in the production of new products (Scarlat et al., 2019).

The Sims Municipal Recycling Facility in New York City, USA, one of the largest MRFs in North America, utilizes advanced sorting technologies like optical scanners and automated conveyor systems to segregate and recover recyclables (Li et al., 2022).

Landfills are a cornerstone of solid waste management systems, serving as primary disposal sites for non-recyclable and non-compostable waste materials. They represent engineered facilities designed to safely contain and manage waste while minimizing environmental impacts (Owusu-Nimo et al., 2019). The Puente Hills

Landfill in California, USA implemented a landfill gas (LFG) recovery system to capture methane emissions generated from decomposing organic waste within the landfill, which is then converted into renewable energy (Lau, 2023).

1.5 Solid waste characterization

Solid waste characterization is crucial in establishing waste management strategies, enabling authorities to devise efficient disposal methods, recycling programs, and energy recovery systems (Miezah et al., 2015). Parameters such as Total solids, volatile solids, moisture content, bulk density, and calorific value are used to characterize solid waste (Zoroufchi Benis et al., 2019).

Total Solids represent the total mass of solids in a waste sample, including both organic and inorganic components (Igoni et al., 2008). Volatile Solids (VS) refer to the portion of solids that can be volatilized at a specific temperature, typically around 550°C. VS analysis helps identify the organic component of solid waste, which is crucial for evaluating its biodegradability and potential for anaerobic digestion or composting (Tokmurzin et al., 2020).

Moisture Content influences waste handling processes and treatment efficiency. High moisture content in waste increases transportation costs, leachate production, and landfill space requirements. Conversely, low moisture content enhances the potential for incineration and energy recovery (Tupsakhare et al., 2020). Accurate moisture content analysis enables waste managers to optimize storage, transportation, and treatment operations effectively (Fatimah et al., 2020).

Bulk Density represents the mass of solid waste per unit volume, indicating its compactness or porosity (Shinners & Friede, 2018). Understanding bulk density is critical for waste storage, transportation, and landfill design. Higher bulk densities imply greater material compaction, reducing storage space and transportation costs (Shinners & Friede, 2018).

Calorific value (heating value or energy value) is the amount of energy released during the complete combustion of a substance. It is typically expressed in units such as kilojoules per kilogram (kJ/kg) or British thermal units per pound (BTU/lb) (Ozyuguran et al., 2018). The calorific value of solid waste varies significantly depending on its composition, generally, materials with higher organic content, such as food waste, paper, and wood, tend to have higher calorific values compared to non-organic materials like plastics and metals (Nwoke et al., 2020).

1.6 Solid waste management in Nigeria

The solid waste management status in Nigeria is marked by several challenges, including deficient policy frameworks, inadequate financing, and a lack of waste data and institutional arrangement (Ezeudu, et al., 2021). The current system suffers from inefficiency due to uncoordinated and poorly planned waste management strategies (Salami et al., 2019). In Lagos State, the rate of waste generation exceeds the capacity of the existing management strategies (Chidiebere et al., 2018). While the present solid waste management strategy is widely employed, it faces challenges such as population growth, urbanization, and industrialization (Nwosu & Chukwueloka, 2020). Despite these challenges, there is potential for adopting a circular economy and utilizing thermochemical conversion to convert waste-to-energy, thereby generating electricity (Salami et al., 2019; Ezeudu, et al., 2021).

Nigeria generates an estimated annual waste of 32 million tonnes annually with a 20 – 30% collection rates and a suggested per capita waste generation of 0.5kg per day (Adeniran et al., 2019; Gbadebo et al., 2022). High population increase in the country has led to an increase in solid waste generation due to housing, manufacturing industries and trade where some cities (Ibadan, Onitsha and Lagos) in Nigeria have been listed as the dirtiest places to live in the world (Ike et al., 2018). The low collection rates evidenced by waste piles on properties, drains and streets are the jurisdiction of the local authorities (Ike et al., 2018).

1.7 Solid waste management status, perception and awareness

Fereja & Chemeda, (2022) conducted a research on the status, quantification and characterization of municipal solid waste in Dilla town of southern Ethiopian as a measure towards effective solid waste management. Data collection was achieved via structured questionnaires on waste management practices from households. On-site investigations, waste segregation, and quantification were conducted. Per capita waste generation rate of 0.475 kg/capita/day was recorded, with organic waste comprising 68.40% by weight, recyclables of 5.5% and 19.60% inert fraction. Challenges identified included poor waste segregation, unsanitary landfill disposal and awareness deficit among residents. Barriers to effective Solid Waste Management (SWM) included inadequate waste fee systems, lack of trained personnel, improper collection routes, vehicle shortages, illegal disposal, and improper community container placement.

Household waste practices and perceptions of solid waste management in Panji, sub-district in Kota Bharu, Kelantan, Malaysia was assessed using a questionnaire survey across 338 households. The results of the study indicate that 95.9% of the respondents have awareness of the improper solid waste management repercussions and 50.3% of the households separate their waste at source for treatment purposes (Fadhullah et al., 2022).

Ike et al. in 2018 carried out an assessment of the status of solid waste across three cities in Nigeria – Enugu, Birnin Kebbi and Minna. Interviews, observations and questionnaires were administered to determine physical composition, collection and disposal situation. It was found that disposal methods adopted were predominantly placing at the government designated containers and sites (52%) and open dumping on roads, drainages and other open spaces. 53% of the waste is collected and transported by the private informal sector using carts while 47% was achieved by the local authorities.

A study by Bundhoo in 2018 assessed the current status of solid waste management in least developed countries and the findings show average generation of 0.56 kg/capita/day with the highest waste stream of 52% being organics and 26% recyclables. Illegal practices of open dumping and burning are recorded due to low and irregular waste collection rates. The few existing landfills were severely lacking in effective leachate or gas collection systems, with a few existing small scale composting and biogas plants, while recycling is carried out for exportation.

Kumar & Agrawal (2020) conducted a research on Municipal Solid Waste Management (MSWM) in India. They highlighted challenges arising from exponential population growth, urban density, cultural diversity, and changing lifestyles. The study identified challenges such as unsorted waste, societal attitudes, poor assessment, and inadequate strategies. The study emphasized the importance of centralized and decentralized solutions involving municipalities, informal sectors, and private agencies to achieve sustainable MSWM in Indian cities by adopting treatment and recycling strategies tailored to India's waste composition.

In a study by Olukanni et al. (2020), the public perception and attitudes towards local waste management practices in five Local Government Areas of Ogun State, Nigeria, were examined. The research utilized a survey to analyze socio-demographics, household characteristics, and solid waste disposal practices. Findings highlighted the influence of factors such as age, income, and education on perceptions and practices, with 36.6% disposing waste at open dumps. The study emphasizes the need for enhanced enforcement of environmental laws and awareness campaigns to promote proper waste management practices.

Mbah et al. (2017) assessed the active role of the informal waste economy based on an 8-year engagement in Nigerian cities. They advocate for integrating informal waste workers into Municipal Solid Waste Management (MSWM) policies, highlighting the significance of social acceptance and inclusion in post-2015 development goals. The paper called for a coherent MSWM policy in Nigeria aligned with the sustainable development goals (SDGs) to enhance livelihoods and sustainability.

In a similar finding by Olukanni & Nwafor (2019), partnerships between local governments and private operators were evaluated. The study highlighted that successful public-private partnerships relied on effective monitoring by the public sector to ensure private operators prioritized service quality over profit while stressing the importance of stakeholder engagement. Legislation and enforcement were also identified as crucial aspects of Solid Waste Management (SWM), ensuring proper waste disposal practices in Nigeria. The public sector played a vital role in facilitating private sector engagement through legislation, enforcement, and public awareness campaigns.

Several studies conducted on solid waste management in Nigeria, Ethiopia, India, and other regions emphasize the need for comprehensive research on the status of solid waste management in Nigeria looking into solid waste quantification, and characterization as well as the existing practices. Despite numerous insights into the challenges and potential solutions, there remains a critical gap in understanding the current state of waste management practices, particularly in Nigerian cities. This gap calls for focused research efforts aimed at assessing waste generation rates, composition, collection methods, and the effectiveness of existing practices and strategies.

Based on the study by Bundhoo (2018), waste generation and composition; waste transport, transfer and collection; waste management techniques; recycling and disposal need to be assessed to establish solid waste management status. Also, perceptions, practices and awareness are an integral part of the solid waste management status for modeling and prediction in the case of scarce data for proper management (Kolekar et al., 2016; Harir et al., 2017; Fadhullah et al., 2022).

2. Materials and Methods

2.1 Study Area

The status of solid waste management was assessed in Bauchi and Kaduna metropolis as 2 of the 19 states in Northern Nigeria. Bauchi state is located at latitude 10° 17’ and longitude 09° 49’ E, with a total land area of 49,119 km^2. The population of Bauchi State in 2015 was estimated at 6,275,523, derived from the 2006 census figure of 4,653,066, indicating a growth rate of 3.6%. (Ori et al., 2021). Bauchi states consists of 20 local government areas of which Bauchi town is among. The major economic activities of Bauchi town are retail and whole sale trading, peasant and commercial agriculture, infrastructural investment such as hotels, construction, factories, private and government firms among others, small scale businesses and other informal trades such as street hawking.

Kaduna state is located at latitude 09° 02'N and 11° 32'N and longitude 06° 15'E and 08° 38'E with a total land area of 46,053 square kilometers. Based on the population projection for the year 2021, Kaduna State is estimated to have a population of 9.4 million individuals, constituting approximately 4.3% of Nigeria's entire population (Abdussalam et al., 2023). The state was ranked number four by total area of land and number three by population. Kaduna state has 23 local government areas with Kaduna city being the capital of the state and described as 8th largest city in the country as of 2006. Farming and other forms of agriculture, small and medium scale businesses are the major economic activities taking place in the city with other manufacturing and processing businesses.

2.2 Sample size determination

Statistical technique was used to determine the sample size at 95% confidence level with 0.05 allowable error. The sample size (n) of households selected to participate in the survey was calculated using the widely utilized equation established by Cochran (1977), which is commonly adopted by numerous researcher (Fereja & Chemeda, 2022).

$$n = \frac{NZ^2pQ}{d^2(N-1) + Z^2pQ} \qquad Eq. 1$$

Where n = sample size of housing units
p = Variable of residential housing unit
Q = nonresidential houses (offices, schools, etc.) = 1 – p
N = Number of housing units (total)

2.4.2 Bulk density

The bulk density of the waste was determined by obtaining the mass of 25 bin bags containing the waste in a container of 0.12 m^3 volume. After obtaining the mass, the density was determined using an equation; $Bulk\ density = \frac{mass}{volume} \qquad Eq. 4$

2.4.3 Moisture content

Moisture content was measured from mass loss of sample after 2 hours at 105^{0}C in an oven under nitrogen purge. Solid waste sample was weighted before and after oven drying to establish the moisture content using Eq 5

$$\%MC = \frac{Wc - Dc}{Dc - W} \times 100 \qquad Eq. 5$$

Where

Wc is the weight of the wet sample + container

Dc is weight of sample (oven dried) + container

W is the weight of the container

MC is the Moisture Content

2.4.4 Volatile solids

Volatile solid was determined by heating the oven dried samples covered with lid in a muffle furnace at 850^{0}C. N_2 purge line and thermocouple were inserted through the top of the furnace and down into the stainless steel box through a small hole in the box cover. The box was purged with N_2 for about 5mins at a flow rate of 5Lm^{-1}. After the initial purge, the N_2 flow rate was decrease to 3 Lm^{-1}, the furnace was set to the desired peak separation temperature of 850oC. The temperature in the furnace was measured every 60s during the heating period and the furnace switched off once the separation temperature is attained. The sample was weighed and the VS determined using Eq. 6

$$Volatile\ solid = \frac{Wtotal - Wvolatile}{Wtotal - Wdish} \times 100 \qquad Eq. 6$$

Where

Wdish = Dish Weight in mg

Wtotal = dried residue Weight and dish weight in mg

Wvolatile = Residue weight and dish weight after ignition in mg

2.4.5 Total solids

Total solid was determined by heating the sample in an evaporating dishes at 550^{0}C for 1 hour in a muffle furnace purged with N_2 for over 10 minutes at a 1 L min^{-1} flow rate of to ensure removal of all oxygen, the sample was transferred immediately to desiccator, left to cool for 10 minutes and weighed. This was done continuously until constant weight was realized then the oven was turned off.

$$Total\ solids = \frac{Wtotal - Wdish}{Wsample - Wdish} \times 100 \quad Eq. 7$$

Where;

Wdish = Weight of dish (mg)

Wsample = Wet sample Weight and dish weight in mg

Wtotal = dried residue Weight and dish weight in mg

2.4.6 Calorific value

The Bomb Calorimeter (Model 6100, Bomb Calorimeter, Parr Instrument, and Moline, Illinois) was used to calculate the sample's Calorific Value. By burning a known mass of standard benzoic acid, which has a known heat of combustion of 26.453 Kj/g, the Bomb calorimeter was calibrated. Using an oxygen bomb calorimeter, the gross heat of combustion was determined in accordance with ASTM D2382-88 standard technique. One milliliter of deionized water and a weighted sample weighing roughly 0.1 grams were added to the calibrated adiabatic bomb calorimeter. In order to ignite the sample, a Chromel (chromium nickel alloy) wire was attached to the two electrodes in the pressure vessel (bomb) and brought into contact with it. The bomb was then put together, sealed, and purified twice by pressurizing it to 0.5 MPa with pure oxygen (99.99%), venting it afterwards, then pressurizing it to 2.0 MPa for the test using pure oxygen. Finally, it was placed inside an insulated jacket-clad bath that held two liters of water. To maintain a consistent temperature throughout the water around the bomb, a motorized stirrer was inserted into the water bath. After that, an electric current was run through the Chromel wire to ignite the sample, which caused it to burn completely in the high-pressure oxygen. Then, to act as a thermal shield, the bomb and the bucket were placed inside a calorimeter jacket. Depending on the unit used, the result was shown in either (Cal/g) or (MJ/kg) on the display.

2.4.7 Current practices, awareness and perception of solid waste management

A structured questionnaire was administered in a structured survey to household residents. This method was employed to gather data on the prevailing waste management practices and awareness by evaluating sorting of waste at source, practices of temporary storage, types of waste disposal, willingness to sort at source, re-use, in situ treatment, waste management awareness, and willingness to pay for proper waste management. Other data encompass gender, age, educational level, marital status, family size, income level. These questionnaires consisted of both open-ended and closed-ended questions. Physical field observation was carried out to assess the current practice of solid waste management in the area.

3. Results and Discussion

3.1 Sample size

100 houses were identified for the survey in both Bauchi and Kaduna with the population of 669 and 675 respectively

3.2 Solid Waste Quantity and Composition

The daily waste generation ranges from 0.18 kg/capita to 0.28 kg/capita in Bauchi and 0.33 kg/capita to 0.36 kg/capita in Kaduna with an average of 0.25kg/capita and 0.35 kg/capita in Bauchi and Kaduna respectively. These generated rates are in close range with the suggested waste generation value of 0.5kg/capita.day in Nigeria by Adeniran et al., (2019) and Bakare (2022). Also similar to the findings in Dilla (Southern Ethiopia) of 0.475kg/capita day, 0.35 kg/capita day in Bonga town of Ethiopia, 0.18 kg/capita day from Bishoftu town, 0.43 kg/capita day from Gondar town of Ethiopia and 0.233 Kg/capita day for East African cities developed by WHO (Fereja & Chemeda, 2022).

Table 2: Waste Generation in Kaduna and Bauchi

Kaduna			**Bauchi**	
Days	Daily total weight (kg)	Daily per capita generation (kg/capita.day)	Daily total weight (kg)	Daily per capita generation (kg/capita.day)
Day 1	239.03	0.35	173.78	0.26
Day 2	239.95	0.36	129.93	0.18
Day 3	226.46	0.34	173.01	0.26
Day 4	228.23	0.34	163.95	0.25
Day 5	232.28	0.34	161.91	0.24
Day 6	224.42	0.33	184.33	0.28

Day 7	245.65	0.36	186.32	0.28
Average		0.35		0.25

The generated solid waste in Kaduna (Fig 3) is predominantly food waste at 53.5%, other fractions include plastics (18.24%), textile (4.48%), paper (2.14%), green waste (2.02%), metals (0.62%), glass/ceramics (0.61%) and other waste (18.41%). Similarly, solid waste generated in Bauchi was found to be food waste (47.1%), plastics (16.5%), green waste (2.5%), paper (3.3%), textile (7.7%), metals (0.9%), glass/ceramics (1%) and other waste (21%) as shown in Figure 3

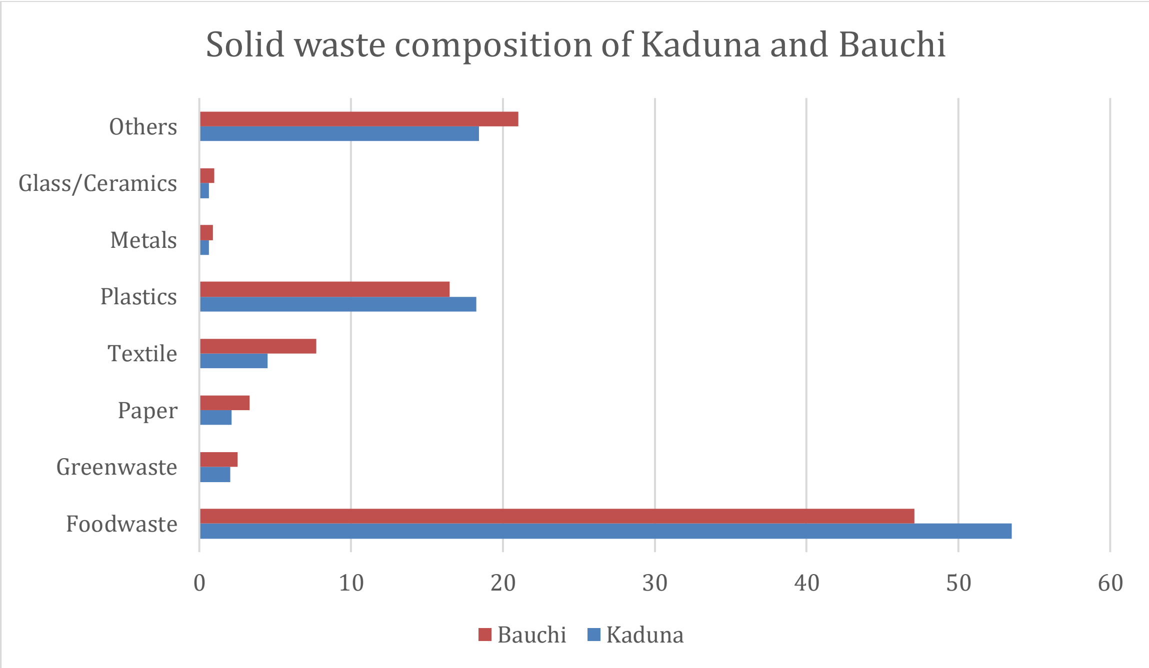

Figure 3 Solid waste composition Kaduna and Bauchi

3.3 Solid Waste Characterization

3.3.2 Bulk density

Table 3: Bulk density of solid waste in Kaduna and Bauchi

	Bulk density (kg/m3)	**Weight of solid waste (kg)**		**Bulk density (kg/m3)**	**Weight of solid waste (kg)**
Kaduna	408.7	49.04	**Bauchi**	398.5	47.82
	357.7	50.08		436.3	52.35
	459.7	55.16		415.2	49.82
	458.8	55.06		408	48.96
	385.1	46.21		398.3	47.8
	410.3	49.23		388.7	46.64
	418.6	50.23		409.3	49.12

*Average bulk density is 412.3 kg/m^3 and 407.8 kg/m^3 for Kaduna and Bauchi respectively
*volume of the solid waste is 0.12m^3

The uncompacted bulk densities of solid waste in Kaduna range from 357.1 kg/m^3 to 459.7 kg/m^3 with an average of 412.3 kg/m^3 (Table 2). That of Bauchi is in the range of 388.7 kg/m^3 to 436 kg/m^3 and 407.8kg/m^3 average. These values are higher than bulk density obtained in Dilla town Ethiopia of 317 kg/m^3, and lower than

480kg/m^3 reported by Singh et al., (2021). That may be as a result of different compositions of waste fractions of the various sources.

3.3.3 Moisture content

The moisture content of the waste is 60% and 40% in Bauchi and Kaduna respectively, these values fall within the ranges of typical solid waste moisture content of middle and low income countries established at 40-60% and 40-80% respectively.

3.3.4 Volatile solids

The average values of volatile content of the waste in Kaduna is 46% and that of Bauchi is 50%, these values indicate the potentials of the waste for energy generation, and close to what was obtained by Singh et al., (2022) with volatile content value of 65%.

3.4.5 Calorific value

The calorific values obtained are similar to works by previous researchers such as Franjo, et al. (1992) with 10.36 MJ/kg from unsegregated solid waste, Nwoke, et al., (2022) with 13.9MJ/kg, 16.3MJ/kg, 26.9MJ/kg and 17.8MJ/kg from sorted solid waste separated into Food waste, paper, plastics and textile respectively. Values of 10.3MJ/kg and 18MJ/kg were obtained in Kaduna and Bauchi respectively. Therefore, a reasonable amount of energy can be obtained through thermal conversion of the waste.

3.5 Practices, awareness and perception of solid waste management

From the result of the survey, only 2% of the households in Kaduna partially sort their waste while no source separation was recorded in Bauchi. However, responses from the households' show 35% and 41% of the respondent that are willing to separate waste at source in Bauchi and Kaduna respectively.

In Kaduna, 20% of the household temporarily store their waste in plastic bags, 75% in bins/drums, while 5% dispose their waste directly into rivers behind their houses. Similarly, 80% of the households in Bauchi store their waste in bins/drums, while 17% use bin bags and 3% dispose waste directly at nearby dump site.

Analysis of the survey shows that 13% and 27% of the households in Bauchi and Kaduna reuse the plastic bottles in their waste. The research considered responses from households and physical observation to ascertain the level of solid waste treatment. While zero waste treatment was recorded at household levels, willingness to treat waste was found to be 60% that may be due to lack technical knowhow recorded at 95%. Also, 86% of the respondents show readiness to make financial commitments towards proper management of their waste. Results of the survey indicate 95% community's eagerness to learn more about waste management.

30% of the households employ the services of private waste collectors to dispose their waste, while 60% dispose their waste at communal dump sites that are often evacuated by large trucks to the central dump site of the town. The remaining households dump their waste in the streams waiting for storm water to transport it somewhere, and the lesser percentage open- burn their waste in their houses. Uncontrolled open dumps, open burning, dumping of refuse by road side or in streams are some common practices of disposal in the study area as seen in figures 4, 5, 6 & 7, causing bad odour, poor aesthetic, health and safety challenges

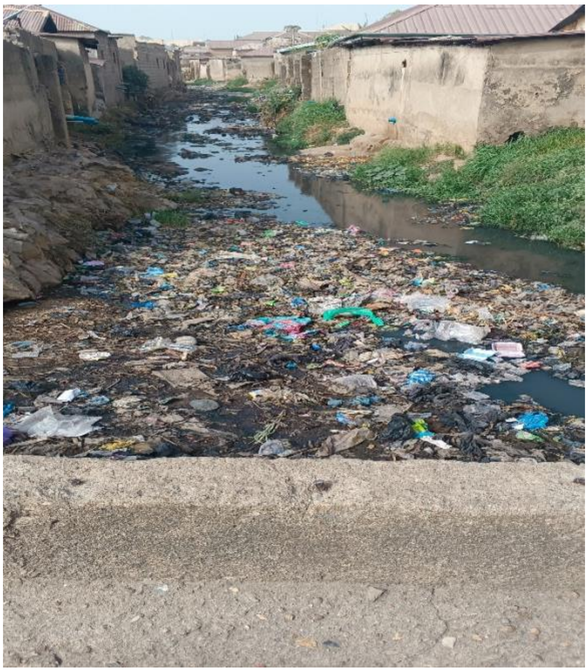

Figure 4: Dumping in stream in Kaduna

Figure 5: Open waste disposal site in Bauchi

Figure 6: uncontrolled waste disposal in Kaduna

Figure 7: dumping in streams in Kaduna

4. Conclusion

The study sheds light on the solid waste generation rates and composition in Kaduna and Bauchi, revealing an average daily waste generation of 0.3 kg/capita/day, aligning closely with national and international findings. The densities of un-compacted solid waste of 412.3kg/m^3 and 407.8kg/m^3 were slightly higher than observed in Dilla town, Ethiopia, indicating variations influenced by waste composition. Food waste emerged as the predominant component in both towns' waste streams, underscoring the need for targeted management strategies.

Furthermore, analysis of parameters such as Total Solid (TS), Volatile Solids (VS), Moisture content, and Calorific Value provided insights into potential energy recovery and handling.

The status of solid waste management highlighted significant challenges, including low rates of waste sorting at the source, inadequate temporary storage methods leading to environmental hazards, and limited waste re-use and treatment practices. The predominant disposal methods of open dumping and burning pose environmental and health risks, emphasizing the urgent need for improved waste management infrastructure and awareness campaigns. Despite these challenges, the community's willingness to engage in proper waste management practices underscores the potential for positive change through education and implementation of effective waste management.

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Optimizing Materials and Building Design for The Circular Economy in Bali: A Case Study of Architectural Projects

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Abstract
Through case studies of architectural projects, this article explores how Bali's circular economy is supported by the optimization of building materials and design. The circular economy seeks to increase resource reuse and reduce waste. This study examines architectural projects that incorporate circular economy concepts, like eco-friendly materials and adaptable modular design, using a case study methodology. Data was collected through in-depth interviews, field observations, and analysis of project documents. The results show that recycled bamboo reduces carbon emissions by up to 40% and new materials by up to 50%, while recycled concrete reduces carbon emissions by 30% and new aggregates by 35%. Additionally, it has been demonstrated that flexible modular designs increase resource efficiency by 25% and decrease construction waste by up to 30%. Collaboration between governments, developers, and local communities is essential in supporting the successful implementation of circular economy principles. These findings guide architectural and engineering professionals to apply the circular economy concept, creating more sustainable and efficient buildings.

Keywords: Circular Economy, Environmentally Friendly Materials, Modular Design, Sustainable Architecture, Bali, Waste Reduction, Resource Efficiency

1. Introduction

The circular economy has become an increasingly popular approach in various sectors, including architecture, to reduce environmental negative impacts. As a significant tourist destination, Bali is responsible for maintaining ecological sustainability. Many architectural projects in Bali are starting to implement the circular economy concept by utilizing recycled materials and designs that consider the life cycle of buildings.

The circular economy aims to minimize waste and maximize resource reuse. In the context of architecture, sustainable material selection and innovative design are key to achieving these goals. This concept not only reduces the environmental impact but also improves the cost efficiency and quality of the building.

This study investigates how building design and construction in Bali might include the concepts of the circular economy. Best practices for eco-friendly materials and design tactics that promote the circular economy are identified in the study. This study offers insights into practical methods for maximizing cutting-edge materials and designs that eventually contribute to a more sustainable built environment through case studies of architectural projects in Bali.

Bali, with its rich cultural background and dependence on the tourism sector, faces significant challenges in maintaining sustainability. The application of circular economy in architecture not only helps to reduce negative impacts on the environment but also provides economic added value for local communities. Building designs that take into account the product lifecycle can help reduce operational and maintenance costs, as well as increase the lifespan of buildings.

This study uses a case study method by analyzing several architectural projects in Bali that have applied circular economy principles. Data was collected through interviews with architects, developers, and industry observers, as well as analysis of project documents. The results show that the use of environmentally friendly materials such as recycled bamboo and concrete, as well as the flexible, disassemblable modular design, provide significant benefits in reducing waste and improving energy efficiency. The study also found that collaboration between various stakeholders, including governments, developers, and communities, is critical to successfully implementing the circular economy in architecture.

Thus, this study provides practical guidance for architectural and engineering professionals to apply the circular economy concept in their projects. The findings of this research can encourage more architectural projects in Bali to adopt circular economy principles, thereby creating a more sustainable and efficient built environment in the future.

2. Literature Review

2.1. Circular Economy in Architecture

The circular economy is a strategy that seeks to reduce waste and the strain on natural resources by establishing a closed system in which goods and materials are optimized for recycling, reuse, or renewable energy. The circular economy is being applied in architecture through the use of eco-friendly materials, designs that permit destruction and reuse, and building life cycle planning.

Numerous studies have demonstrated that incorporating the circular economy into design can have a number of advantages, such as lower carbon emissions, more cost effectiveness, and higher-quality buildings. For instance, studies conducted by Fatimah et al. (2023) and Ramakrishna (2021) demonstrate that using the concepts of the circular economy in the building industry can result in a 40% reduction in greenhouse gas emissions. Additionally, this strategy can lessen dependency on new raw materials and increase building operations' energy efficiency (Martin Geissdoerfer et al., 2017; Taş et al., 2017).

2.2. Environmentally Friendly Materials

Eco-friendly materials are a key element in the circular economy. These materials typically have a longer life cycle, are recyclable, and have a lower environmental impact than conventional materials. Some examples of eco-friendly materials commonly used in architecture include bamboo, recycled wood, recycled concrete, and natural composite materials.

For example, bamboo is a fast-growing, strong, and flexible material. According to (Sharma et al., 2015), bamboo has a tensile strength comparable to steel, making it a good choice for environmentally friendly building structures. In addition, the use of recycled concrete is also becoming more and more popular. Research by (Pacheco-Torgal, 2014) shows that recycled concrete can reduce the use of natural aggregates and the energy needed to produce new concrete.

2.3. Modular and Flexible Design

Building components that may be disassembled and reassembled are made possible by the flexible and modular design. This method allows for flexibility in space planning and utilization while upholding the circular economy's tenets. Construction waste is greatly decreased by the modular design, which enables building components to be reused at different locations or in other projects.

By using reused components, modular design has been demonstrated to enhance resource efficiency and cut down on construction time and expenses (Garusinghe et al., 2023; Jayawardana et al., 2023; Wuni et al., 2022). Furthermore, because of its adaptable design, the building may be made to meet the evolving needs of its users, extending its lifespan and raising its market value.

2.4. Building Life Cycle

The circular economy concept highlights how crucial it is to take into account a building's whole life cycle, from design and construction to operation and recycling and demolition. Architects and developers can design solutions to lessen a building's environmental effect across its whole life cycle by taking this into account.

(Blengini et al., 2010) emphasized that Life Cycle Assessment (LCA) is an important tool to evaluate the environmental impact of buildings. LCA helps identify stages where interventions can be undertaken to reduce emissions and waste, as well as improve resource efficiency.

2.5. Multi-stakeholder Collaboration

The implementation of the circular economy in architecture requires collaboration between various stakeholders, including governments, developers, architects, and communities (Garusinghe et al., 2023; Jayawardana et al., 2023; Turner et al., 2021). This collaboration is important for creating supportive policies, developing new technologies, and increasing public awareness and participation in sustainable projects.

According to (Murray et al., 2017)multi-stakeholder collaboration can accelerate the implementation of the circular economy by integrating different perspectives and expertise, as well as driving innovation in building design and construction. Governments can play an important role by providing incentives and regulations that support sustainable practices (Li et al., 2023; MacKenbach et al., 2020; Zhuang et al., 2023).

3. Research Methods

This study uses a case study approach to analyze the implementation of circular economy principles in architectural projects in Bali. Cases are selected based on criteria such as the use of environmentally friendly or recycled materials, the implementation of modular or flexible designs, and the involvement of multi-stakeholder collaboration. Data is collected through in-depth interviews with architects, developers, and other stakeholders, field observations at project sites, and analysis of project documents such as design plans and development reports.

The data collected was analyzed using a qualitative approach through coding, categorization, and thematic analysis stages to identify themes and patterns related to the circular economy (Djamba et al., 2002; Jamshed, 2014; Neuman, 2011; Skarbek, 2020; Toloie-eshlaghy et al., 2011; Welch et al., 1992)Results are validated through data triangulation, member checking, and peer review to ensure consistency and reliability of information. This comprehensive methodological approach provides an in-depth overview of best practices in applying circular economy principles and generates recommendations for architectural and engineering professionals to improve the sustainability of their projects.

4. Result and Discussion

This article examines the application of circular economy principles in architectural projects in Bali with a focus on material optimization and building design. This study uses a case study method by analyzing several architectural projects that have applied circular economy principles. The results show that using environmentally friendly materials and flexible modular design significantly reduces waste, improves resource efficiency, and reduces carbon emissions.

4.1. The use of environmentally friendly materials

The use of environmentally friendly materials, such as recycled bamboo and concrete, significantly reduces environmental impact.

Table 1: Use of Environmentally Friendly Materials and Carbon Emission Reduction

Material	Project	New Material Reduction (%)	Carbon Emission Reduction (%)
Recycled Bamboo	Ecological Villa	50%	40%
Recycled Concrete	Green Hotel	35%	30%

Source: Author Analysis, 2024.

The case study in Table 1 shows that using recycled bamboo in the Villa Ecological project can reduce carbon emissions by 40% and reduce the use of new materials by up to 50%. Similarly, using recycled concrete in the Eco Hotel project reduced the use of new aggregate by 35% and reduced carbon emissions by 30%.

Figure 1: The Use of Recycled Bamboo in Ecological Villa Projects in Bali
Source: Documentation 2024

Figure 1 depicts a sustainable villa in Bali built using recycled bamboo materials. It features traditional Balinese architectural elements with a touch of modern design. The villa structure includes open spaces, large bamboo pillars, walls, and thatched roofs, surrounded by tropical plants and lush gardens.

The use of eco-friendly materials not only reduces carbon emissions but also improves cost efficiency. Recycled bamboo, for example, is cheaper than conventional construction materials and has a longer life cycle. Recycled concrete also offers similar advantages, reducing the cost of raw materials and energy required to produce new concrete.

4.2. Modular and Flexible Design

The flexible modular design allows building components to be dismantled and reused in other projects, reducing construction waste and improving resource efficiency. The case study in Table 2 shows that this design can reduce construction waste by up to 30% and improve resource efficiency by 25%.

Table 2: Modular and Flexible Design in Architectural Projects

Project	Modular Design	Construction Waste Reduction (%)	Resource Efficiency (%)
Modular Community Center	Yes	30%	25%
Green Office	Not	15%	10%

Source: Author Analysis, 2024.

The Modular Community Center project uses a modular design that allows the building to be dismantled and reassembled in another location. Modular components are manufactured in factories and assembled on construction sites, reducing construction time and material waste. This case study shows that the use of modular design can reduce construction waste by up to 30% and improve resource efficiency by up to 25%.

Figure 2: Modular Design at a Community Center in Bali
Source: Documentation 2024

Figure 2 depicts a community center in Bali with modular design elements. The building features modular units interconnected with sustainable materials, open spaces, and natural lighting. Traditional Balinese architectural details such as wood carvings and bamboo structures are also integrated, creating a harmony between modern modular design and cultural aesthetics.

The Green Office Project uses traditional construction methods without modular design. Although the project also applies several sustainability principles, such as using environmentally friendly materials and energy efficiency, it can only reduce construction waste by 15% and resource efficiency by 10%. This shows that modular design has more significant advantages regarding resource efficiency and waste reduction.

4.3. Multi-stakeholder collaboration

Collaboration between various stakeholders greatly influences the success of implementing circular economy principles. Table 3 shows that projects involving governments, developers, and communities show improved resource efficiency and sustainability. This collaboration includes joint planning, supportive policy development, and active community participation.

Table 3: Multi-Stakeholder Collaboration in Architecture Projects

Project	Stakeholders Involved	Collaboration Results
Green Hotel	Government, Developers, Communities	Improved Resource Efficiency
Ecological Villa	Developer, Community	Construction Waste Reduction
Modular Community Center	Government, Developers, Communities	Improving Project Sustainability

Source: Author Analysis, 2024.

Figure 3: Collaborative Projects in Bali

Source: Documentation 2024.

Figure 3 illustrates a collaborative architecture project in Bali involving the government, developers, and local communities. The project features sustainable buildings with traditional Balinese elements, green spaces, and renewable energy sources. There was a group of people, including officials, architects, and members of the local community, who discussed and worked together on the project. The surrounding environment includes lush tropical vegetation and a well-planned layout that integrates modern and traditional design.

4.4. Discussion

The findings demonstrate that incorporating circular economy concepts into Bali's architectural projects offers a number of advantages, such as lower carbon emissions, more resource efficiency, and less trash generated during construction. It has been shown that using eco-friendly materials, such bamboo and recycled concrete, can significantly lessen the impact on the environment. Reusing building components is another benefit of the flexible and modular design, which lowers waste and boosts productivity. The effective use of circular economy ideas also heavily depends on cooperation amongst different stakeholders. To develop new technologies, raise public awareness, and encourage public involvement in sustainable initiatives, governments, developers, and communities must collaborate. The study also highlights a number of obstacles to the circular economy's adoption, such as the need for more education and awareness campaigns as well as the creation of laws and incentives that encourage environmentally friendly behavior. More work is required to teach experts in the industry and include the idea of the circular economy into engineering and architecture curricula.

5. Conclusion

This study looks at how Bali's architectural projects use the concepts of the circular economy, with an emphasis on building design and material optimization. The examined case studies demonstrate how using eco-friendly materials and adaptable modular designs may significantly reduce construction waste, increase resource efficiency, and lower carbon emissions.

Use of Eco-Friendly Materials:
1. Recycled Bamboo: The case study of Ecological Villa shows that the use of recycled bamboo can reduce the use of new materials by up to 50% and carbon emissions by 40%. Bamboo has the advantage of being a fast-growing, strong, and high-carbon absorbing material.
2. Recycled Concrete: The Eco-Friendly Hotel Project shows that recycled concrete can reduce the use of new aggregate by 35% and carbon emissions by 30%. Recycled concrete reduces construction waste and offers cost efficiency and sustainability.

Modular and Flexible Design:
1. Waste Reduction: The modular design allows building components to be dismantled and reused in other projects, reducing construction waste by up to 30%.
2. Resource Efficiency: This design increases resource efficiency by 25% as modular components can be mass-produced and installed quickly on construction sites.
3. Flexibility and Adaptability: The modular design allows the building to adapt to changing space needs, extending its lifespan and reducing the need for major renovations.

Multi-Stakeholder Collaboration: Governments, developers, and communities are just a few of the stakeholders whose cooperation is crucial to the effective application of circular economy principles. In order to develop new technologies, create regulations that support them, and raise public knowledge and engagement in sustainable projects, this partnership is crucial.

Challenges and Recommendations:
1. Awareness and Education: Architecture and engineering professionals need to be more aware of and educated about the benefits of the circular economy. Integrating circular economy concepts into educational curricula can help prepare a generation of more environmentally conscious professionals.
2. Development of Policies and Incentives: Governments must develop policies and provide incentives to support using environmentally friendly materials and modular designs. Construction regulations and standards also need to be adjusted to support sustainable practices.
3. Collaboration and Innovation: Encourage collaboration between developers, architects, and governments to address the challenges of implementing a circular economy. Innovation in technology and design is also needed to improve the project's efficiency and sustainability.
4. The application of circular economy principles in architecture in Bali shows promising results in reducing environmental impact and improving resource efficiency.

Professionals in engineering and architecture can use the study's conclusions as a guide for implementing the circular economy concept in their projects. The building industry can progress toward a more efficient and sustainable built environment in the future by implementing these techniques more widely. This study concludes that the circular economy is an effective and necessary approach in architecture to achieve long-term sustainability. Implementing the strategies identified in this study can help professionals create buildings that are not only environmentally friendly but also economical and adaptive to future changes.

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Integrating Artificial Intelligence in Architectural Education for Sustainable Development: A Case Study in Bali

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Abstract
In the era of rapid technological advancement, Artificial Intelligence (AI) plays a vital role in architecture and education. In Bali, the challenge lies in adopting modern technologies while preserving cultural heritage through sustainable development. This study investigates the integration of AI into architectural education to enhance sustainable practices while maintaining traditional values. A case study approach was employed, and data was collected through interviews and observations at universities in Bali. The findings indicate that AI significantly improves design efficiency, reducing completion time from three months to one month and increasing building energy efficiency from 70% to 85%. Additionally, AI facilitates cultural preservation by enabling the digital documentation and application of traditional elements, guided by the Tri Hita Karana philosophy, which emphasizes a balance between humans, nature, and spirituality. However, concerns from some stakeholders suggest that AI may diminish architects' creative roles, highlighting the need for a balanced approach where technology supports, rather than replaces, human creativity. The research underscores the importance of educational curricula integrating AI without compromising cultural identity, ensuring sustainable architectural practices in Bali. The study offers valuable insights for academic institutions, policymakers, and industry stakeholders, showcasing how tradition and technology can coexist. It concludes that AI integration effectively supports sustainability while preserving Bali's cultural heritage, fostering synergy between innovation and tradition to address sustainable development challenges. These findings contribute to developing an educational framework that promotes innovation and cultural preservation in architectural design.

Keywords: Artificial Intelligence, Architectural Education, Sustainable Development, Balinese Architecture

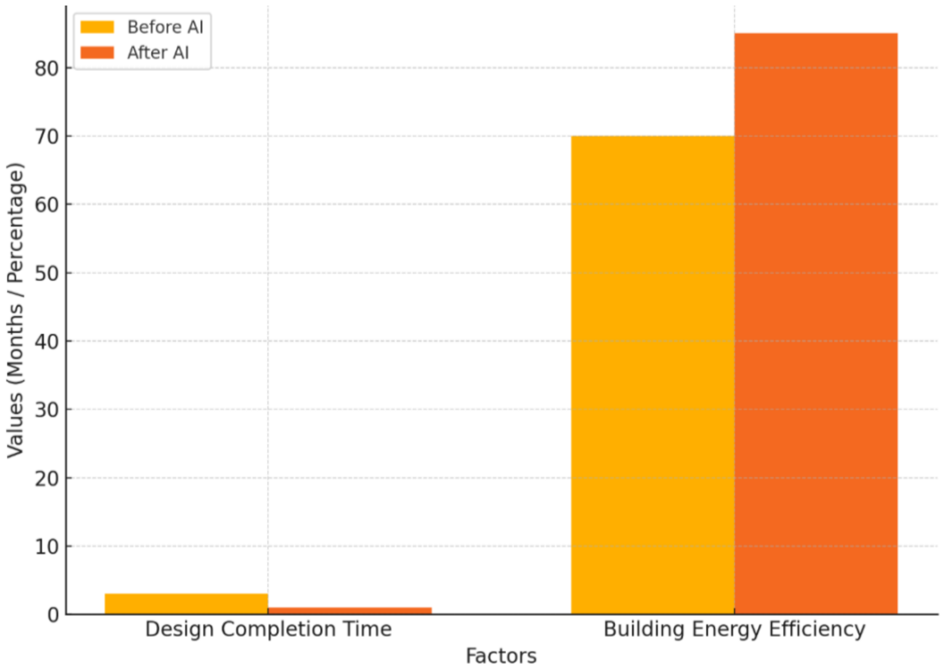
1. Introduction

1.1. Background

Technological developments, particularly Artificial Intelligence (AI), have significantly impacted various disciplines, including architecture and education. In the context of sustainable development, AI offers innovative solutions that enable designers to improve efficiency, accuracy, and precision in designing eco-friendly buildings. As an international tourist destination with high cultural value, Bali faces the challenge of maintaining local architectural traditions while adopting modern technology (Arief, 2019; Adams, 2018). Therefore, the integration of AI in architecture education can be a bridge between traditional heritage and technological innovation to achieve sustainable development.

The application of AI in architecture education can also facilitate the creation of designs that consider the *Tri Hita Karana* principle, which is the balance between humans, nature, and God. However, this technology must be applied carefully so as not to sacrifice the Balinese cultural identity, which is an essential part of tourism attraction and local development (Putra, 2018). This emphasizes the importance of AI adaptation that aligns with local wisdom.

The urgency of this research lies in the urgent need to create a sustainable built environment in Bali amid the development of AI technology. There is still a lack of research on how AI can be used in locally-based architecture education. By improving design efficiency and helping to preserve traditional architecture, AI integration is believed to play an essential role in supporting sustainable development goals in Bali.



Graph 1: Comparison of Time and Energy Efficiency Before and After AI Deployment

Previous research results show that AI can reduce design time by up to 67%, from three months to one month, while improving building energy efficiency by up to 85% (Miller, 2019; Zhang, 2021), as shown in Graph 1. This fact underscores the potential for AI to be adapted in architecture education at local universities to strengthen the application of sustainable architecture concepts. The following graph shows the positive impact of applying AI in architectural design (Smith & Jones, 2014; Lee & Park, 2021).

1.2. Research Question

This research seeks to answer two main questions: How can AI be integrated into architecture education in Bali to support sustainable development? Second, how does AI integration impact preserving Balinese traditional architecture in supporting sustainable development? These questions aim to explore the synergy between technological development and cultural preservation so modern educational practices can be aligned with sustainability principles without neglecting Bali's rich architectural heritage.

1.3. Research Objectives

This research examines the application of AI in architecture education and its impact on sustainable development in Bali. It is hoped that the results of this research can encourage the synergy between technology and tradition in Balinese architecture to create a harmonious collaboration between modern innovation and local wisdom. In addition, this research is expected to provide guidelines for educational institutions to integrate AI into the architecture curriculum to improve the efficiency and quality of learning. Furthermore, this research aims to build awareness of the importance of AI adaptation that respects local cultural values so that technological developments can go hand in hand with efforts to preserve traditions and cultural identities that are the foundation of Balinese architecture. Thus, integrating AI in architecture education is expected to support Bali in facing the challenges holistically and sustainably facing sustainable development challenges facing sustainable development challenges.

1.4. Research Gaps and Significance

Although research on the application of AI in architecture has increased in developed countries, the focus of studies in local contexts such as Bali is still minimal (Rabinowitz, 2021). Most research centers on technological aspects and innovation in countries with more advanced educational and technological infrastructure without considering local social and cultural factors. Research in Indonesia, including in architecture education, also shows that the application of technology has not fully paid attention to traditional and local aspects (Widjaja, 2020). This creates a significant gap in understanding how AI can be effectively applied in architecture education in Bali while still maintaining local cultural identity and traditional wisdom.

Therefore, this study aims to fill this gap by examining the integration of AI in architecture education in Bali. This research focuses on how AI improves efficiency and effectiveness in the learning and design process and plays a role in preserving essential elements of traditional Balinese architecture. In this context, this research offers a new perspective that is relevant and contextual, considering that Bali is a world tourist destination committed to combining modernity with cultural preservation.

In addition, the research is significant for local stakeholders, including educational institutions, governments, and the architecture industry, in ensuring that technological adaptations align with preserving traditions (Matsuda, 2021; Turner & Brown, 2020). In the long term, collaboration between technology and tradition is expected to strengthen Bali's competitiveness as a sustainable tourism destination and balance modernity and local wisdom. Thus, this research contributes to the development of architectural education that is not only innovation-oriented but also culturally and environmentally responsible.

2. Literature Review

2.1. Theoretical and Conceptual Studies

Artificial Intelligence (AI) has become an important innovation in modern architecture due to its ability to speed up the design process and enable more efficient modeling of buildings. According to (Thompson, 2021;

Mitchell, 2020), AI helps architects produce more precise and innovative designs and can also analyze data in real time to provide design improvement recommendations. Technologies such as *machine learning* and *generative design* allow the exploration of hundreds of design iterations quickly, reducing reliance on time-consuming manual processes. As such, AI is making a significant contribution to contemporary architecture, particularly in terms of efficiency and design innovation.

In addition, the concept of sustainable development, popularized by (Brundtland, 1987) through *Our Common Future*, emphasizes the importance of meeting the needs of current generations without compromising the ability of future generations to meet their needs. In architecture, this concept translates into environmentally friendly and economical buildings that support social welfare. Technologies such as AI play an essential role in realizing sustainable development by optimizing building design to save energy and resources and minimizing adverse environmental impacts on the environment.

On the other hand, traditional Balinese architecture is based on the principle *of Tri Hita Karana*, which is the balance between humans, nature, and God, embodied in conventional buildings' layout and orientation (Putra, 2018). this principle requires that every building respects the relationship between humans and the surrounding environment and adheres to spiritual and cosmological values. The biggest challenge in modern architecture in Bali is how to keep this principle relevant, especially when technologies such as AI begin to be applied in the architectural design process (West, 2019; Kvale & Brinkmann, 2015). Therefore, it is essential to ensure that technological innovation goes hand in hand with preserving traditional values so that Balinese cultural identity is not eroded.

2.2. Previous Research Review

Previous studies have shown the potential of AI to support the efficiency of the architectural design process. Zhang (2021) found that AI could reduce design completion time by 67%, from three months to one month, while improving the energy efficiency of buildings from 70% to 85%. AI also plays a role in optimizing the use of materials and resources, directly impacting the sustainability of architecture. This research confirms that AI can be essential in realizing more efficient and sustainable architectures.

However, research in Indonesia, as presented by (Widjaja, 2020; Anderson, 2018), shows that technology integration in architecture education is still limited to standard design software and has not touched the comprehensive application of AI. In addition, the focus of the research has not considered cultural and local aspects, especially related to traditional Balinese architecture. This creates a significant gap in understanding the application of AI in the context of architectural education in Bali, where aspects of tradition and local wisdom are essential factors that cannot be ignored.

Furthermore, Kim &Lee (2020) and Rabinowitz (2021) stated that although technology integration in architectural education in developed countries is increasing, its application in local contexts such as Bali faces various challenges. These challenges include limited technological infrastructure and resistance from more traditional stakeholders to change. Thus, this research is expected to offer practical and contextual solutions for architecture education in Bali, especially in bridging technological innovation with preserving architectural traditions.

2.3. Relevance of Literature to Research Question

This literature review supports the formulation of a research problem that focuses on how AI can be integrated into architecture education in Bali and its impact on preserving traditional architecture. AI integration is expected to support sustainable development goals while maintaining local cultural identity. From the literature reviewed, it is clear that the research gap lies in the application of AI in architecture education that considers local cultural factors and traditions. Therefore, this research aims to ensure that technological innovation increases efficiency and supports sustainability and preservation of artistic values. Bali can maintain its position as a tourist destination and sustainable cultural center in the modern era.

3. Research Methods

This research uses a qualitative method with a case study approach, considered appropriate for exploring a deep understanding of the application of artificial intelligence (AI) in architecture education in Bali. This approach was chosen because case studies allow researchers to study specific phenomena in natural contexts in detail (Creswell, 2014). This research focuses on how AI can be integrated into the architecture curriculum and its impact on the sustainable development and preservation of Balinese traditional architecture.

3.1. Data Collection Methods

Data collection in this study was carried out using several techniques so that the information obtained was rich and valid. The first technique is an in-depth interview with lecturers and students from universities in Bali who have adopted AI in architecture education. This interview explores respondents' experiences and perceptions regarding AI's benefits, challenges, and impacts on educational practices and architectural design. In-depth interviews are very effective in digging into respondents' subjective understanding and identifying the factors influencing the application of AI (Kvale & Brinkmann, 2015).

In addition, participatory observation of classes and design projects that use AI as part of the learning process is carried out. This observation provides direct insight into the interaction between students, lecturers, and technology in the learning environment. The researcher also noted how AI helps improve design efficiency and how the technology contributes to preserving architecture based on *Tri Hita Karana*, which is the balance between humans, nature, and God (Putra, 2018). Participatory observation helps researchers understand the application of AI in the context of local cultures and practices in more depth.

The third data collection technique is the analysis of documentation, such as curriculum, syllabus, and student design projects, to assess the extent to which the integration of AI in architecture education has been implemented. This documentation also examines the consistency between theory and practice in education and how AI supports sustainable development goals in Bali (Brundtland, 1987).

3.2. Data Analysis Methods

The data obtained were analyzed using thematic analysis methods, which allowed the identification of key themes in the collected data. This method facilitates the grouping of data based on categories such as the integration of AI in learning, challenges in preserving traditional architecture, and their impact on sustainable development (Braun & Clarke, 2006). For example, interviews with lecturers and students will be categorized into specific themes, such as the effectiveness of using AI and resistance to modern technology from some of the more traditional stakeholders.

Thematic analysis also helps highlight essential patterns in the AI integration process, such as how this technology accelerates the design process from three months to one month and improves energy efficiency by up to 85%, as found by Zhang (2021). In addition, this method allows researchers to understand the challenges faced, such as the constraints of AI adaptation on traditional architectural projects and concerns that using AI could reduce architects' creative role in design.

3.3. Data Validity and Reliability

To ensure validity and reliability, this study applies data triangulation, namely comparing the results of interviews, observations, and documentation to see the consistency of information (Patton, 2002). In addition, member-checking is carried out by providing feedback on the results of interviews to respondents to ensure accurate interpretation of data and reduce researcher bias. This technique helps reinforce the findings' validity and ensures that the data generated represent the respondent's experience and perception objectively.

3.4. Relevance of Method to Research Question

This research method is relevant to formulating a problem that emphasizes how AI can be integrated into architecture education in Bali and its impact on preserving traditional architecture. The use of in-depth interviews and participatory observation allows researchers to explore in detail the experiences and perceptions of lecturers and students regarding the application of AI. Thematic analysis helps identify patterns and challenges that arise to connect modern technology with the preservation of local culture. Thus, this method provides a comprehensive framework for answering research questions and producing findings that can make a practical contribution to the improvement of architectural education in Bali.

4. Results and Discussion

4.1 Results

The study found that the application of AI in architecture education in Bali has significantly impacted the efficiency and sustainability of the design process. Based on data collected from interviews and observations at universities in Bali, students reported that AI helped speed up the design process and reduce errors common in manual processes. To illustrate, the design turnaround time that previously took three months was reduced to just one month after the implementation of AI. In addition, the energy efficiency of AI-aided designed buildings increased from 70% to 85%.

Table 1: The Impact of Applying AI in Design Processes and Energy Efficiency

Factor	Before the Adoption of AI	After the Adoption of AI
Design Completion Time	3 Months	1 Month
Building Energy Efficiency	70%	85%

Source: Author Analysis, 2024.

Table 1 compares performance before and after the implementation of AI. The findings show that:

1. Design Turnaround Time: After the implementation of AI, the time required to complete an architectural design is significantly reduced from 3 months to just 1 month. This shows that AI can speed up the design process by providing analysis and recommendations automatically and more efficiently.
2. Building Energy Efficiency: AI-powered designs have increased energy efficiency from 70% to 85%. AI helps optimize the selection of materials, building layout, and energy systems, making buildings more energy-efficient and environmentally friendly.

This increase shows that integrating AI in education and architectural practices accelerates design and supports sustainability by producing more energy-efficient buildings. This data aligns with sustainable development, emphasizing resource efficiency without sacrificing quality and functionality.

In addition to increasing efficiency, AI also facilitates the preservation of traditional architecture by digitizing complex cultural elements. Elements such as Balinese carvings and building layouts based on the Tri Hita Karana principle can now be documented and integrated digitally. This project allows students to use 3D modeling technology to understand and apply cultural elements to their architectural designs.

However, the study also identifies several challenges faced in the application of AI. One of the main challenges is resistance from some stakeholders who are worried that AI will reduce architects' creative role. They argue that AI can replace some of the essential artistic and human aspects of the architectural design process.

4.2. Discussion

This study's findings align with a literature review that states that AI can improve efficiency and accuracy in the architectural design process [24]. As Zhang (2021) points out, the application of AI can speed up the design process by up to 67%, and these findings align with research data showing a decrease in design time from three months to one month. The increase in building energy efficiency from 70% to 85% also strengthens the role of AI in supporting sustainable development goals (Brundtland, 1987).

Applying AI in architecture education in Bali helps increase efficiency and supports preserving local culture. The digitization of traditional elements, as analyzed by Putra (2018), allows students to understand and apply the principles of *Tri Hita Karana* in their designs, thus ensuring that technological innovations do not sacrifice Balinese cultural identity.

However, resistance to the application of AI also reflects the challenge mentioned by Rabinowitz (2021), namely the concern that technology can replace human creativity. This underscores the importance of a balanced approach to integrating AI, where technology serves as a tool to strengthen creativity and innovation rather than replacing the role of humans in the design process.

In this context, educational institutions should design a curriculum that focuses on technology and preserving cultural values. Thus, students can learn how to use AI effectively without losing the essence of creativity and cultural identity in their designs. This strategy will ensure that the application of AI in architecture supports sustainable development while maintaining local cultural richness.

These findings confirm that integrating AI in architecture education in Bali improves design efficiency and sustainability and helps preserve traditional culture. Despite the challenges in its implementation, with the right approach, AI can be a powerful tool to create synergies between modern technology and local traditions. This supports the research's goal of promoting sustainable development through adaptive and contextual architecture education.

5. Conclusion

5.1. Conclusion

This research successfully answers two main questions related to integrating Artificial Intelligence (AI) in architecture education in Bali and its impact on sustainable development and preservation of traditional architecture. The results show that the application of AI significantly improves efficiency in the architectural design process. The design turnaround time was reduced from three months to one month, while the building's energy efficiency increased from 70% to 85%. These findings align with Zhang (2021), in research, which confirms that AI can accelerate the design process and optimize resource use, supporting sustainable development goals (Brundtland, 1987).

In addition to supporting efficiency and sustainability, AI integration also plays a role in preserving Balinese traditional architecture. This technology facilitates digitizing complex cultural elements, such as Balinese carvings and spatial planning based *on Tri Hita Karana* (Harison, 2021; Putra, 2018). Thus, AI serves as a tool to strengthen the synergy between tradition and technological innovation in architecture in Bali.

However, the study also found challenges in the form of resistance from some stakeholders worried that AI would reduce architects' creative roles. These concerns reflect the need for a careful approach to the application of AI, where technology should be used as a supporting tool and not as a substitute for human creativity [6].

Overall, this study shows that AI can be effectively integrated into architecture education in Bali to support sustainable development without neglecting the preservation of local cultural values.

5.2. Recommendations

Based on the study's findings, there are several essential recommendations for various stakeholders to maximize the benefits of applying AI in architecture education. Educational institutions are advised to strengthen the architecture curriculum by adding specific modules regarding AI and its application in sustainable architectural design. This step will help students understand the potential of these technologies in supporting design efficiency and sustainability. In addition, the architecture faculty must collaborate with technology study programs to enrich the learning process through cross-disciplinary integration. In the process, AI must be positioned as an aid, not a substitute, to ensure that student creativity remains a key aspect of architectural design development. The development of architectural design development, the development of, the development of architectural design development, the development of the development of architectural design development, the development of the, the development of architectural design development, the development of the development of architectural design development, the development of the, the development of the development of architectural design development, the development of the architectural design.

Governments and policymakers urgently need policies encouraging technology integration in education, such as providing subsidies or incentives to universities that develop AI-based programs. This policy must also involve Indigenous communities and local stakeholders so that technological innovation remains aligned with local wisdom and traditions, especially in Bali. Thus, technology can be applied contextually without neglecting the cultural values that are the foundation of traditional Balinese architecture.

From the perspective of the architecture and design industry, adopting AI technology in architectural projects can improve the efficiency and sustainability of buildings. In addition, AI should be promoted as a tool that supports collaboration between tradition and modernity in design, especially in regions like Bali with a high cultural wealth. Thus, AI is a technical tool and a catalyst for creating innovative and contextual designs.

5.3. Recommendation for Further Studies

This research also provides some suggestions for future studies. First, quantitative research on a broader scale is highly recommended to obtain more accurate data related to the impact of AI on sustainability and creativity. Surveys with a more significant number of respondents will provide deeper insights into the application of AI in various universities. Second, a long-term impact analysis is needed to explore how AI application affects students' creative skills and the role of architects in the industry sustainably.

In addition, a comparative study of the application of AI in Bali and other regions with different cultural and educational characteristics will provide insight into the variation and adaptation of technology in various contexts. Finally, future research must highlight ethical and copyright aspects of using AI, especially related to ownership of designs co-generated by humans and technology. This is important so that the application of AI does not cause legal or ethical problems in the architectural design process.

By implementing these recommendations and continuing research in the future, it is hoped that AI can continue to be effectively integrated into architecture education. This implementation will support sustainable development goals and preserve local culture and traditions in Bali. Technology and tradition can combine to create an innovative and sustainable architectural future.

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