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Technical Skills for Enhancing Self-Employment in Brazing Among Mechanical Engineering Craft-Practice Students in Technical Colleges in Rivers State

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Abstract

The study ascertained the extent to which students were exposed to technical skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State. Five research questions raised and corresponding five null hypotheses formulated guided the study. The descriptive survey research design was adopted for the study. The population comprised seven trainers and three workshop attendants in four government approved Government Technical Colleges in Rivers State that offered Mechanical Engineering Craft Practice. Structured questionnaire was used for data collection; it was validated by two research experts. The data collected were analyzed using mean, standard deviation and t-test statistics. From the findings of the study, it was revealed that students were, to a high extent, exposed to all the listed items on good fit and proper clearance. Based on the findings of the study, it was recommended among other things, that the government should encourage students of mechanical engineering craft-practice who have acquired brazing skills to go into small-scale businesses after graduation, as this will enhance self-employment in Rivers State.

Keywords: technical, skills, self-employment, brazing

1. Introduction

The word skill is commonly used to describe the potential to perform a task acceptably. Skill refers to the knowledge, competencies, and abilities required to perform operational tasks (Zhang, 2019). Skills are acquired not only through learning, but through life and work experience. In comparison to concepts that actually indicate just the capacity to develop some capabilities — such as innate talent, competence or intellectual capacity — the word skill generally implies the physical capabilities gained through practice, education, or practical experience (García-Pérez, García-Garnica, & Olmedo-Moreno, 2021). The term skill is used in several fields of study, notably psychology, business management, technology and education, and it has several interpretations, used for a variety of purposes and situations. In psychology, the concept of skill is considered as the extent to which an individual is able to carry out an activity, in terms of proficiency and the rate at which the task is being accomplished. Thus, this notion of skill explains the capabilities possessed by a person, for instance a self-employed, which encompasses mental capacity, physical abilities, understanding and interpersonal competencies. Similarly, researchers in the field of business management consider the term skill as the potentials necessary for accomplishing a given piece of work — in the sense of the extent and the difficulty in accomplishing the work in context, the degree of accuracy shown and time used to accomplish the given task and the know-how and training required to master the work. Lately, the definition of skill has further been

expanded. The significance of "skill set" is emphasized in conjunction to soft skills — communication skills, innovation, adaptability, management, and teamwork. The difference among basic as well as easily adaptable or crucial skill sets and vocational, job-specific, or technical ability, has equally been highlighted. While generic skills are valuable in a variety of industries, technical skills, such as brazing, are required for self-employment in a specific sector or industry. In contrast to personal skills, that are connected to one's character, technical ability are easily measurable. The latter are skills that can or are evaluated and may require some specialized technical certification. They are any abilities related to a particular task or activity. It entails comprehension, strategies, processes, practices and competency in particular tasks such as brazing.

Thus, brazing is a metal-joining method that entails heating up and running a filler material through the work-piece, with the wire having a smaller melting temperature than the brazed work-piece (Way, Willingham, & Goodall, 2019). It is therefore a broad term that encompasses a wide variety of processes, skills, and facilities for joining objects of different shapes, from huge ships to light engine components and precious ornaments. Contemporary brazing businesses are equipped with a wide range of specialist and multi-purpose tools able to produce extremely accurate and robust results (Weis, Fedorov, Elssner, Uhlig, Hausner, Wagner, & Wielage, 2017).

Brazing has been practiced since by the ancient Egyptians and basic brazing methods started in 2975 BC (Way, Willingham, & Goodall, 2019). At this time, new techniques were introduced and improved upon by the Sumerians, Greeks, and Romans. Before the Eighteenth Century, the Europeans had used the techniques to produce magnificent objects (Way, Willingham, & Goodall, 2019). Precious metals, bronze, and copper were among the most prevalent materials.

Brazing has significant advantages above all other metal-joining methods, like welding (Daly, 2013). Because brazing cannot soften the metal parts to be joined, it permits for very much stricter accuracy regulation and generates a good quality joint without any need for intermediate completion. Dissimilar metals and non-metals for example, sintered metal ceramic materials, can also be brazed. Due to the uniform heating of a brazed item, brazing provides less thermal deformation than welding. Dynamic and multi arrangements can be brazed at a low cost. Welded joints must be ground flush at key moments, which is an expensive supplementary task that brazing somehow does not involve since it provides a smooth joint. A further benefit is that brazing can be completely covered or clad for protection. Finally, because the independent process variables are less susceptible to problems, brazing is readily applied to mass manufacturing and quick to optimise.

Brazing is different from other metal joining techniques due to its operation at very high temperatures (above the melting point of the filler metal), does not soften the metal parts to be joined and parts are better closely fitted than in most methods, such as soldering and welding. When brazing operation is carried out, the filler metal — by capillary action — runs into the space between the substrates to be joined. Obviously, this is achievable when the filler metal is heated beyond its melting point under controlled conditions, especially in an atmosphere of flux. The key feature of brazing is its capacity to join similar or dissimilar metals with appreciable mechanical strength. Ultra quality parts joined by means of brazing require proper cleaning of parts by techniques such as pickling and, the parts be also closely fitted (Daly, 2013). Pan, and Zhao (2017), recommended joint clearance of 0.032 – 0.08 mm for good capillary actions, high joint strength and better quality. However joint clearances of up to 0.6 mm are common in most brazing operations.

Thus, there are basic mechanical engineering craft skills, such as brazing sills, which all trainees of mechanical engineering craft-practice in technical colleges in Rivers State are expected to master to ensure quality joint finishes, consistency, hermeticity and reliability (Isaac & Obed, 2020). Some of the skills, as outlined by Daly (2013), include good fit and proper clearance, cleaning of metal, assembling parts for brazing, brazing the assembled parts and cleaning the brazed joint.

Good fit and proper clearance are essential requirements for efficient brazing operations. They are necessary for the free flow (capillary action) of the hot, liquid filler metal that joins the base metals. In order to disseminate the hot liquid filler material between the layers of the base metals, brazing uses the capillarity principle. The tensile strength of the brazed junction varies with the distance between the components being attached (Etemadi, *et al* 2012). The strength of the joint is, however, almost reduced to that of the filler metal if the gap is wider than is necessary. According to Daly (2013), capillary action can function at different levels of clearance. How much room there needs to be for expansion and contraction depends on the kind, size, and design of the metals being joined as well as the joint itself. To create a brazed junction that is extremely durable and strong, the work-pieces must be carefully cleaned before brazing. Cleaning the work-piece is essential for the capillary activities of the filler metal, which are necessary for efficient brazing. The impurities serve as a barrier between the brazing materials and the base metal surface when they are utilised without being cleaned. Cleaning the part to be brazed is an activity that does not require much to carry out, though, it must be carried out in the right manner. Different techniques of cleaning are applied in different conditions.

After brazing, a workpiece needs to be cleaned. The post-brazing cleaning procedure involves two steps: removing flux residues and pickling to get rid of any oxide scale that formed during the brazing process. Flux may be able to endure pressure testing, but it might not be able to seal pinholes in a braze joint under pressure. But as soon as they were used, the joints would leak. Any remaining flux will pull any water from the environment that is present because some fluxes have the capacity to absorb water, which will result in the work-piece rusting. Flux after brazing can be difficult to remove because it creates a surface that is hard and glass-like.

2. Statement of the Problem

Students in mechanical engineering craft practice are expected to be self-employed and employers of labour upon graduation (Ehimen & Ezeora, 2018). However, the reverse seems to be the case. This is clear from the fact that 44.1% of technical and commercial graduates are still out of work, neither employed nor self-employed (Nigerian Economic Alart, 2020). As noted by Mgaiwa (2021), however, this is due to several factors, notably the lack of practical training necessary for the acquisition of practical skills required for self-employment. Thus, graduates from technical colleges acquire little knowledge and practical skills that can enable them, on graduation, to practise what they have learned in school, create jobs for themselves, and participate in economic development (Okafor, in Ubele & Okwelle, 2020).

Obviously, this is a defect in academics, and the effects have been proven to be increasingly damaging economically, politically, socially, etcetera (Audu, Kamin, & Balash, in Ubele & Okwelle, 2020). As Essien & Onukwubiri (2015) pointed out, unemployed graduate youths have become vulnerable to illegal activities and anti-social behaviour. Their female unemployed graduates are the hardest hit, as many of them have turned to illegal activities such as prostitution and circumstantial marriages to make ends meet. On the other hand, their male counterparts are forced by circumstance to engage in illegal activities in order to survive.

Therefore, addressing this issue will provide Rivers State Technical Colleges with much-needed insights to enable them to improve their policies, strategies, and curriculum to incorporate more of the technical skills required to encourage self-employment among Students. Hence, the problem of the study is: what are the technical skills required to enhance self-employment in brazing among engineering craft practise students in technical colleges in Rivers State?

2.1 Purpose of the Study

The purpose of the study was to ascertain the extent to which students were exposed to technical skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State. In terms of objectives, the study sought to ascertained;

1) The extent to which good fit and proper clearance skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
2) The extent to which metal pre-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
3) The extent to which parts assembly skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
4) The extent to which brazing operation skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
5) The extent to which brazed joint post-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

2.2 Research Questions

The following questions were posed to guide the study;

1) To what extent do good fit and proper clearance skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
2) To what extent do metal pre-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
3) To what extent do parts assembly skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
4) To what extent do brazing operation skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
5) To what extent do brazed joint post-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

2.3 Hypotheses

The following null hypothesis were formulated and tested at .05 level of significance.

1) There is no significant difference between the mean responses of trainers and workshop attendants on the extent to which good fit and proper clearance skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
2) There is no significant difference between the mean responses of trainers and workshop attendants on the extent to which metal pre-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
3) There is no significant difference between the mean responses of trainers and workshop attendants on the extent to which parts assembly skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
4) There is no significant difference between the mean responses of trainers and workshop attendants on the extent to which brazing operation skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.
5) There is no significant difference between the mean responses of trainers and workshop attendants on the extent to which brazed joint post-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

3. Conceptual Review

3.1 Good Fit and Proper Clearance Skills

The effectiveness of brazing depends on maintaining proper joint clearance, as capillary action is optimized when the gap between workpieces is around 0.0015 (0.038 mm) (Etemadi et al., 2012). Deviations from this clearance — whether too tight or too wide — reduce joint strength (Estrella, 2021). Additionally, thermal expansion coefficients must be considered, especially for dissimilar metals, to ensure dimensional stability during heating (Daly, 2013). Joint designs, such as butt and lap joints, influence strength, with lap joints offering greater bonding surfaces for heavier loads (Sharma et al., 2016). Electrical conductivity and pressure-tightness requirements may also dictate joint design and filler metal selection (Wu et al., 2021).

3.2 Metal Pre-Cleaning Skills

Proper cleaning is essential for successful brazing, as contaminants like oil, grease, rust, and scale hinder filler metal flow (Nawfel, 2020). Cleaning should follow a sequential process: degreasing first, followed by oxide removal via mechanical or chemical methods (Baranowski et al., 2019). Flux application immediately after cleaning prevents recontamination and oxide formation during heating (Winiowski & Majewski, 2012). The choice of flux depends on brazing conditions, with boron-modified fluxes enhancing high-temperature performance (Way et al., 2019).

3.3 Parts Assembly Skills

Proper assembly ensures alignment during brazing, with gravity or fixtures used to maintain joint clearance (Wang et al., 2021). Fixtures should minimize heat conduction and use materials like stainless steel or ceramics (Muhammad et al., 2018). Self-supporting designs, such as crimping or riveting, reduce fixture dependency (Weis et al., 2017). Sharp edges should be softened to facilitate filler metal flow (Jayesh & Harshwardhan, 2017).

3.4 Brazing Operation Skills

Brazing involves heating the assembly to filler metal flow temperature, with torch brazing being common for separate assemblies (Kay, 2018). Uniform heating is critical, and filler metal should be applied near the joint to ensure capillary flow (Rocha & Handerson, 2019). Safety measures include using proper regulators, check valves, and flashback arrestors (Ngai & Ngai, 2020). Ventilation is necessary to mitigate toxic fumes from fluxes and filler metals (Zhang et al., 2013).

3.5 Brazed-Joint Cleaning Skills

Post-braze cleaning removes corrosive flux residues and oxide scale, typically via hot water quenching or chemical pickling (Wojdat et al., 2019). Residual flux compromises joint inspection, promotes corrosion, and hinders coatings (Savill & Eifion, 2021). Mechanical or ultrasonic cleaning may be used for stubborn residues (Zhao et al., 2021). Acid baths should be carefully selected to avoid damaging the joint (De Prado et al., 2016).

3.6 Review of Related Empirical Studies

For over two decades, the Nigerian government has emphasized skill development as a strategy to enhance youth self-employment and reduce unemployment (Oluwajodu et al., 2015). Research has explored the relationship

between skill acquisition and entrepreneurial intentions, particularly among technical and vocational students. Oluwajodu et al. (2015) investigated this link among undergraduate students in Nigeria's north-central region, finding a strong positive correlation between skill development and entrepreneurial intent. The study recommended equipping students with entrepreneurial skills to foster self-employment.

Similarly, Edmond et al. (2014) examined strategies for empowering individuals through Technical, Vocational Education, and Training (TVET). Their survey highlighted the importance of public-private partnerships in funding and managing TVET programs to enhance self-employment opportunities. The study underscored the need for adequate training resources and institutional support.

Ehijele and Ugochukwu (2018) focused on metalworking skills among technical college graduates in Edo and Enugu States. Their findings revealed that graduates required competencies in interpreting technical drawings, using measurement tools, and operating machinery. The study advocated for improved workshop facilities and qualified instructors to bridge skill gaps.

Odinaka (2017) expanded on this by assessing entrepreneurial skills for metalwork students in Northeast Nigeria. The research identified 40 essential skills and called for government investment in infrastructure and curriculum development to integrate these competencies.

Bala et al. (2022) explored welding and fabrication skills in Jigawa State, noting deficiencies in practical abilities like torch handling and metal joining techniques. The study recommended enhanced training and provision of modern welding equipment to improve craftsmanship.

Lastly, Ubele and Okwelle (2020) analyzed machining skills for metalwork students in Rivers State, emphasizing the role of teachers in communicating skill relevance and encouraging small-scale entrepreneurship post-graduation. Their findings supported government interventions to promote self-employment among graduates.

Collectively, these studies highlight the critical role of skill development in reducing unemployment, stressing the need for institutional support, updated curricula, and public-private collaboration to foster youth entrepreneurship in Nigeria.

4. Methodology

The descriptive survey research design was adopted for the study. The study was carried out in Rivers State. Rivers is one of the states in southern Nigeria. The population for the study was technical colleges in Rivers State. There were four government approved Technical Colleges (GTC) in Rivers State: GTC Port Harcourt, GTC Tombia, GTC Ele-Ogu and GTC Ahoada. However, only GTC Port Harcourt, GTC Tombia, and GTC Ahoada offered mechanical engineering craft practice, with trainers and workshop attendants populations of; GTC Port Harcourt (4, 1), GTC Tombia (1, 1) and GTC Ahoada (2, 1), which summed-up to 10 (Records Unit, Rivers State Secondary School Board, 2022). The mechanical engineering craft practice trainers were considered suitable as part of the population for the study because they are experts in teaching concepts on brazing and related topics in technical colleges. Similarly, the workshop attendants were used as part of the population for the study because they are qualified personnel with a wealth of experience on the trade, and more so, they are vast on the skills essential for maintenance of brazing equipment and preparation of materials for the students (NBTE, 2014).

The study was a census because the entire population was studied. The questionnaire was used as research instrument. The tool was expressly validated by two research experts. Thus, the reliability index was established using Cronbach Alpha coefficient formula which yielded a reliability coefficient of .83. Descriptive and inferential statistics were used to answer the research questions and also test the hypotheses. Specifically, the mean and standard deviation were used to answer the research questions and the results obtained were utilized to make decisions. The decision rule on any weighted mean was as follows;

2.5 and above	Agree
Below 2.5	Disagree

Similarly, the students t-test was used to test the hypotheses at .05 level of significance and the results obtained were used to make decisions based on the following decision rules;

Reject the null hypothesis (Ho) in favour of the alternate hypothesis (Ha), if the calculated value (tc) is greater than the table value (t-crit), otherwise accept the null hypothesis.

5. Results

Research question 1

To what extent do good fit and proper clearance skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

Table 1. Mean responses of trainers and workshop attendants on the extent to which good fit and proper clearance skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State

S/N	Good Fit and Proper Clearance Skills	Trainers			Workshop Attendants		
		Mean	SD	Decision	Mean	SD	Decision
1.	Selecting, cutting and fitting work-pieces considering their thermal expansivities.	4.14	0.38	Agree	4.29	0.53	Agree
2.	Maintaining a clearance of 0.038mm between work-pieces before brazing.	4.71	0.49	Agree	3.77	0.53	Agree
3.	Making a lap joint three times as long as the thinner member's thickness.	4.57	0.79	Agree	4.89	0.32	Agree
4.	Constructing butt joints for brazing works that require high tensile strength.	4.14	0.69	Agree	4.37	0.64	Agree
5.	Holding tubular joints in the correct alignment for brazing, by nesting one tube inside the other.	4.14	0.90	Agree	4.30	0.73	Agree
6.	Increasing joint area by using lap joint.	4.57	0.53	Agree	4.88	0.32	Agree
7.	Using filler wires that contain very good conductors of electricity such as silver, for work-pieces that are intended for use with electricity.	4.29	0.49	Agree	4.53	0.61	Agree
	Grand Mean and SD	**4.37**	**0.61**	**Agree**	**4.43**	**0.53**	**Agree**

Source: Field Survey 2022.

The results of the analysis from research question 1, as presented in Table 1, show that the respondents Agree with items 1-7. However, since the grand means of 4.37 and 4.43 are above the criterion mean of 2.50, therefore it implies that the trainers and workshop attendants Agree that the students were, to a high extent, exposed to the seven items. The standard deviations of 0.61 and 0.53 show high homogeneity or closeness in their responses.

Research question 2

To what extent do metal pre-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

Table 2. Mean responses of trainers and workshop attendants on the extent to which metal pre-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State

S/No	Metal pre-cleaning skills	Trainers			Workshop Attendants		
		Mean	SD	Decision	Mean	SD	Decision
8.	Removing oil or grease by dipping the parts into a suitable degreasing solvent, vapour degreasing or by alkaline or aqueous cleaning.	5.00	0.00	Agree	4.94	0.24	Agree
9.	Removing rust by acid pickle treatment.	4.29	0.49	Agree	4.91	0.29	Agree
10.	Cleaning heavy rust/hard scales by mechanical/ abrasive cleaning using emery cloth, grinding wheel, file or grit blast.	5.57	0.53	Agree	4.33	0.64	Agree
11.	Choosing the right acid and combining same with distilled water in the right proportion, considering the nature of the metal in context.	4.50	0.76	Agree	4.33	0.78	Agree
12.	Neutralizing the leftover acid with appropriate alkaline solution to ensure that no acid traces	4.00	0.58	Agree	4.30	0.48	Agree

	remain in crevices or blind holes.						
13.	Using the right abrasive wheel for cleaning to ensure proper surface roughness.	4.14	0.69	Agree	4.46	0.54	Agree
14.	Using alkaline pickle solution such as sodium hydroxide, for non-ferrous metals and alloys.	4.00	0.82	Agree	4.13	0.87	Agree
	Grand Mean and SD	**4.36**	**0.55**	**Agree**	**4.49**	**0.55**	**Agree**

Source: Field Survey 2022.

The findings from research question 2 are shown in Table 2, which demonstrates that all the respondents Agree with items 8 through 14. The grand means of 4.36 and 4.49, however, are higher than the criterion mean of 2.50, which suggests that the trainers and workshop attendants both Agree that the students were, to a high extent, exposed to the seven items. High homogeneity or closeness in their responses is indicated by the standard deviations of 0.55 and 0.55.

Research question 3

To what extent do parts assembly skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

Table 3. Mean responses of trainers and workshop attendants on the extent to which parts assembly skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State

S/No	**Parts Assembly Skills**	**Trainers**			**Workshop Attendants**		
		Mean	**SD**	**Decision**	**Mean**	**SD**	**Decision**
15.	Producing the right type of joint for any given brazing operation.	4.00	0.58	Agree	3.73	0.80	Agree
16.	Selecting, producing and combining two kinds of joints to improve brazed-joint strength.	4.43	0.79	Agree	4.57	0.63	Agree
17.	Aligning work-pieces for proper/accurate brazing operation.	4.71	0.49	Agree	4.03	0.65	Agree
18.	Producing fixtures for various shapes/sizes of work-pieces.	4.43	0.53	Agree	4.57	0.65	Agree
19.	Identifying intricacies in work-pieces and building fixtures to accommodate them.	4.43	0.79	Agree	4.55	0.75	Agree
20.	Identifying appropriate parts and creating vents in tubular work-places.	3.86	1.07	Agree	4.06	0.87	Agree
21.	Maintaining the right clearance (gap) for effective capillarity of the molten filler metal.	4.86	0.66	**Agree**	4.34	0.67	**Agree**
	Grand Mean and SD	**4.39**	**0.66**	**Agree**	**4.34**	**0.67**	**Agree**

Source: Field Survey 2022.

Table 3 shows that all the respondents Agree with items 15-22 in response to research question 3. However, because the grand means of 4.39 and 4.34 are greater than the criterion mean of 2.50, it means that the trainers and workshop attendants Agree that the students were, to a high extent, exposed to the seven items. The standard deviations of 0.66 and 0.67 indicate a high uniformity or closeness in their responses.

Research question 4

To what extent do brazing operation skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

Table 4. Mean responses of trainers and workshop attendants on the extent to which brazing operation skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State

S/No	Parts Assembly Skills	Trainers			Workshop Attendants		
		Mean	SD	Decision	Mean	SD	Decision
22.	Flowing the molten filler wire into a tubular work piece until it runs out through the veins.	4.57	0.79	Agree	4.54	0.73	Agree
23.	Placing the filler mental at the appropriate position for efficient brazing operation.	3.86	0.69	Agree	4.52	0.60	Agree
24.	Moving the touch continuously to evenly heat up the work piece.	4.44	0.79	Agree	4.27	0.89	Agree
25.	Heating the assembly to the flow point of the brazing filler mental.	4.86	0.38	Agree	4.77	0.56	Agree
26.	Applying the flux from 51 mm to 76 mm to facilitate the flow of molten filler wire into the workpiece.	4.29	0.76	Agree	3.92	0.91	Agree
27.	Wearing the right safety gear before commenting brazing operation.	3.86	1.07	Agree	4.25	0.80	Agree
28.	Connecting the gases only when they are needed to be used.	3.86	0.69	**Agree**	4.59	0.52	**Agree**
29	Opening acetylene before lighting the touch followed by oxygen after the touch has been lit.	4.86	0.38	**Agree**	4.67	0.85	**Agree**
	Grand Mean and SD	**4.32**	**0.69**	**Agree**	**4.44**	**0.73**	**Agree**

Source: Field Survey 2022.

All of the respondents Agree with items 22 through 29, according to the research question 4 result shown in Table 4. The fact that the grand means of 4.32 and 4.44 are higher than the criterion mean of 2.50, however, suggests that the trainers and workshop attendants both Agree that the students were, to a high extent, exposed to the eight items. A high degree of homogeneity or closeness in their responses can be seen in the standard deviations of 0.69 and 0.73.

Research question 5

To what extent do brazed joint post-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

Table 5. Mean responses of trainers and workshop attendants on the extent to which brazed joint post-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State

S/No	Parts Assembly Skills	Trainers			Workshop Attendants		
		Mean	SD	Decision	Mean	SD	Decision
30.	Quenching a workpiece in hot water at 120°F (50°C) to remove brazing Flux.	4.29	0.49	Agree	4.50	0.62	Agree
31.	Brushing the assembly (joint) while it is still hot.	4.57	0.53	Agree	4.46	0.59	Agree
32.	Selecting and using water-based Flux for easier post brazing cleaning.	4.86	0.38	Agree	4.93	0.26	Agree
33.	Changing workpiece cleaning solution occasionally.	4.14	0.69	Agree	4.10	0.80	Agree
34.	Sandblasting work piece to remove debris from it.	4.00	0.82	Agree	4.12	0.87	Agree

35.	Dissolving tough Flux residues in 25% hydrochloric and bath at 140°F to 160°F (60°C to 70° C).	4.00	0.58	Agree	4.71	0.45	Agree
36.	Removing phosphate slag through prolonged pickling in sulfuric acid.	4.14	0.69	**Agree**	4.34	0.68	**Agree**
	Grand Mean and SD	**4.29**	**0.60**	**Agree**	**4.34**	**0.61**	**Agree**

Source: Field Survey 2022.

The findings from research question 5 are shown in Table 5, which reveal that all respondents Agree with items 30 through 36. The fact that the grand means of 4.29 and 4.34 are higher than the criterion mean of 2.50, however, suggests that the trainers and workshop attendants both Agree that the students were, to a high extent, exposed to the seven items. A high degree of uniformity or closeness in their responses is shown in the standard deviations of 0.60 and 0.61.

6. Test of Hypotheses

Hypothesis 1

There is no significant difference between the mean responses of trainers and workshop attendants on the extent to which good fit and proper clearance skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

Table 6. T-test Analysis of the Difference Between the mean responses of trainers and workshop attendants on the extent to which good fit and proper clearance skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State

	N	**X**	**SD**	**DF**	**T-Cal**	**T-Crit.**	**Decision**
Trainers.	7	4.37	0.61				
				8	0.16	1.96	Accept
Workshop attendants.	3	4.43	0.53				

Source: Field Survey.

The data in Table 6 show the calculated T-value (T-cal) of 0.16 at 0.05 level of significance, while T-critical is 1.96. Since the calculated T-value (T-cal) of 0.16 is less than the T-critical value (T-crit) of 1.96, the null hypothesis is accepted. This indicates that there is no significant difference between the mean responses of trainers and workshop attendants on the extent to which students were exposed to good fit and proper clearance skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State.

Hypothesis 2

There is no significant difference between the mean responses of trainers and workshop attendants on the extent to which metal pre-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

Table 7. T-test Analysis of the Difference Between the mean responses of trainers and workshop attendants on the extent to which metal pre-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State

	X		**DF**	**T-Cal**	**T-Crit.**	**Decision**
Trainers.	4.36	0.55				
			8	0.34	1.96	Accept
Workshop attendants.	4.49	0.55				

Source: Field Survey.

The data in Table 7 indicate that the calculated T-value (T-cal) at the 0.05 level of significance is 0.34, while T-critical is 1.96. The null hypothesis is upheld because the calculated T-value of 0.34 is less than the T-critical value of 1.96. This suggests that there is no statistically significant difference between the mean responses of trainers and workshop attendants on the extent to which students were exposed to metal pre-cleaning skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State.

Hypothesis 3

There is no significant difference between the mean responses of trainers and workshop attendants on the extent to which parts assembly skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

Table 8. T-test Analysis of the Difference Between the mean responses of trainers and workshop attendants on the extent to which parts assembly skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State

	N	X	SD	DF	Z-Cal	Z-Crit.	Decision
Trainers.	7	4.39	0.66				
				8	0.11	1.96	Accept
Workshop attendants.	3	4.34	0.67				

Source: Field Survey.

The data in Table 8 show a calculated T-value (T-cal) of 0.11 at 0.05 level of significance, while T-critical is 1.96. The null hypothesis is accepted because the calculated T-value (T-cal), which is 0.11, is lower than the T-critical value (T-crit), which is 1.96. This suggests that there is no statistically significant difference between the mean responses of trainers and workshop attendants on the extent to which students were exposed to metal pre-cleaning skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State.

Hypothesis 4

There is no significant difference between the mean responses of trainers and workshop attendants on the extent to which brazing operation skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

Table 9. T-test Analysis of the Difference Between the mean responses of trainers and workshop attendants on the extent to which brazing operation skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State

	N	X	SD	DF	T-Cal	T-Crit.	Decision
Trainers.	7	4.32	0.69				
				8	0.24	1.96	Accept
Workshop attendants.	3	4.44	0.73				

Source: Field Survey.

Table 9 shows the calculated T-value (T-cal) of 0.24 at the 0.05 level of significance, while the T-critical is 1.96. The null hypothesis is accepted because the calculated T-value (T-cal) of 0.24 is less than the T-critical value (T-crit) of 1.96. This indicates that there is no significant difference between the mean responses of trainers and workshop attendants on the extent to which students were exposed to brazing operation skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State.

Hypothesis 5

There is no significant difference between the mean responses of trainers and workshop attendants on the extent

to which brazed joint post-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State.

Table 10. T-test Analysis of the Difference Between the mean responses of trainers and workshop attendants on the extent to which brazed joint post-cleaning skills enhance self-employment among mechanical engineering craft-practice students in technical colleges in Rivers State

	N	X	SD	DF	T-Cal	T-Crit.	Decision
Trainers.	7	4.29	0.60				
				8	0.39	1.96	Accept
Workshop attendants.	3	4.45	0.61				

Source: Field Survey.

Table 10 shows the calculated T-value (T-cal) of 0.39 at the 0.05 level of significance, while T-critical is 1.96. For the fact that the calculated T-value (T-cal) of 0.39 is less than the T-critical value (T-crit) of 1.96, the null hypothesis is upheld. This indicates that there is no significant difference between the mean responses of trainers and workshop attendants on the extent to which students were exposed to brazed-Joint cleaning skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State.

7. Discussion of Findings

The results or findings of the study are discussed here under one after the other. The findings from research question 1, which sought to assess the extent to which students were exposed to good fit and proper clearance skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State, indicated that selecting, cutting and fitting work-pieces considering their thermal expansivities, maintaining a clearance of 0.038mm between work-pieces before brazing, making a lap joint three times as long as the thinner member's thickness, constructing butt joints for brazing works that require high tensile strength, holding tubular joints in the correct alignment for brazing, by nesting one tube inside the other. And increasing joint area by using lap joint using filler wires that contain very good conductors of electricity such as silver, for work-pieces that are intended for use with electricity were good fit and proper clearance skills students were exposed to during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State. This finding is in agreement with the view of Ubele and Okwelle (2020) that skills are required by students of metalwork in technical colleges for self-employment in Rivers State. The test of the first hypothesis proves that there is no significant difference between the mean responses of trainers and workshop attendants on the extent to which students were exposed to good fit and proper clearance skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State.

The findings from research question 2, which sought to assess the extent to which students were exposed to metal pre-cleaning skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State, indicated that removing oil or grease by dipping the parts into a suitable degreasing solvent, vapour degreasing or by alkaline or aqueous cleaning, removing rust by acid pickle treatment, cleaning heavy rust/hard scales by mechanical abrasive cleaning using grinding wheel, files or grit blast, choosing the right acid and combining them with distilled water in the right proportion considering the nature of the metal and context, neutralizing the leftover acid with appropriate solution to ensure that no acid remains in crevices or blind holes, using the right abrasive wheel for cleaning to ensure proper surface roughness and using alkaline pickle solution such as sodium hydroxide for non-ferrous metals and alloys were good fit and proper clearance skills students were exposed to during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State. This finding is in agreement with the view of Odinaka (2017) that skills are essential for a successful metalworking and self-employment. The test of the second hypothesis proves that there is no significant difference between the mean responses of trainers and workshop attendants on the extent to which students were exposed to metal pre-cleaning skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State.

The findings from research question 3, which sought to assess the extent to which students were exposed to parts assembly skills during training to enhance self-employment in brazing among mechanical engineering

craft-practice students in technical colleges in Rivers State, indicated that producing the right type of joint for any given brazing operation, selecting producing and combining two kinds of joints to improve brazed joint strength, aligning work-pieces for proper/accurate brazing operation, producing fixtures for various shapes/sizes of work-pieces, identifying intricacies in work-pieces and building fixtures to accommodate them, identifying appropriate parts and creating vents in tubular work-places and maintaining the right clearance (gap) for effective capillarity of the molten filler metal were parts assembly skills students were exposed to during training to enhance self-employment in brazing among mechanical engineering craft-practice Students in technical colleges in Rivers State. This finding is in agreement with the view of Oluwajodu et al. (2015) that there is a strong correlation between skill development and entrepreneurial intent. That students must possess skills/abilities in order to participate in entrepreneurial endeavours. The test of the third hypothesis proves that there is no significant difference between the mean responses of trainers and workshop attendants on the extent to which students were exposed to parts assembly skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State.

The findings from research question 4, which sought to assess the extent to which students were exposed to brazing operation skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State, indicated that flowing the molten filler wire into a tubular work-piece until it runs out through the vents, placing the filler metal at the appropriate position for efficient brazing operation, moving the touch continuously to evenly heat up the work-piece, heating an assembly to the flow point of the brazing filler metals applying the flux from 51 mm to 76 mm to facilitate the flow of the molten filler wire into the workpiece, wearing the right safety gear before commencing brazing operation, connecting the gases only when they are needed to be used and opening acetylene before lighting the torch, followed by oxygen, after the torch has been lit were brazing operation skills students were exposed to during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State. This finding is in agreement with the view of Bala, et al. (2022) that there is a need for improvement so that metal workers could develop the skills to hold nozzles securely while working on metal. The test of the fourth hypothesis proves that there is no significant difference between the mean responses of trainers and workshop attendants on the extent to which students were exposed to brazing operation skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State.

The findings from research question 5, which sought to assess the extent to which students were exposed to brazed-joint cleaning skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State, indicated that quenching a workpiece in hot water at 120°F (50°C), to remove brazing flux, brushing the assembly (joint) while it is still hot, selecting and using water-based flux for easier post-brazing cleaning, changing work-piece cleaning solution occasionally, sandblasting a work-piece to remove debris from it, dissolving tough flux residues in 25% hydrochloric acid bath at 140° F-160°F (60°C-70°C) and removing phosphate slag through prolonged pickling in sulphuric acid were brazed-joint cleaning skills students were exposed to during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State. This finding is in agreement with the view of Ehijele and Ugochukwu (2018), that technical college students required knowledge of symbols, how to use tools, and how to read blueprints, among other things. The test of the fifth hypothesis proves that there is no significant difference between the mean responses of trainers and workshop attendants on the extent to which students were exposed to brazed-Joint cleaning skills during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State.

8. Conclusion

Good fit and proper clearance skills students were exposed to during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State, included selecting, cutting and fitting work-pieces considering their thermal expansivities, maintaining a clearance of 0.038mm between work-pieces before brazing, making a lap joint three times as long as the thinner member's thickness, constructing butt joints for brazing works that require high tensile strength, holding tubular joints in the correct alignment before brazing by nesting one tube inside the other, increasing joint area by using lap joint and using filler wires that contain very good conductors of electricity such as silver, for work-pieces that are intended to be used with electricity.

Metal pre-cleaning skills students were exposed to during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State, were removing oil or grease by dipping the parts into a suitable decreasing solvent, vapour decreasing or by alkaline or aqueous cleaning, removing rust by acid pickle treatment, cleaning heavy rust/hard scales by mechanical abrasive cleaning using

grinding wheel, file or grit blast, choosing the right acid and combining it with distilled water in the right proportion considering the nature of the metal in context, neutralizing the leftover acid with appropriate alkaline solution to ensure that no acid remains in crevices or blind holes, using the right abrasive wheel for cleaning to ensure proper surface roughness and using alkaline pickle solution such as sodium hydroxide for non-ferrous metals and alloys.

Parts assembly skills students were exposed to during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State, were the right type of joint for any given brazing operation, selecting producing and combining two kinds of joints to improve brazed joint strength, aligning work-pieces for proper/accurate brazing operation, producing fixtures for various shapes/sizes of work-pieces, identifying intricacies in work-pieces and building fixtures to accommodate them, identifying appropriate parts and creating vents in tubular work-pieces and maintaining the right clearance (gap) for effective capillarity of the molten filler metal.

Brazing operation skills students were exposed to during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State, were flowing the molten filler wire into a tubular work-piece until it runs out through the vents, placing the filler metal at the appropriate position for efficient brazing operation, moving the touch continuously to evenly heat up the work-piece, heating an assembly to the flow point of the brazing filler metal, applying the flux from 51 mm to 76 mm to facilitate the flow of the molten filler wire into the work-piece, wearing the right safety gear before commencing brazing operation, connecting the gases only when they are needed to be used and opening acetylene before lighting the torch, followed by oxygen, after the torch has been lit.

Brazed-joint cleaning skills students were exposed to during training to enhance self-employment in brazing among mechanical engineering craft-practice students in technical colleges in Rivers State, were quenching a work-piece in hot water at 120°F (50°C), to remove brazing flux, brushing the assembly (joint) while it is still hot, selecting and using water-based flux for easier post-brazing cleaning, changing work-piece cleaning solution occasionally, sandblasting a work-piece to remove debris from it, dissolving tough flux residues in 25% hydrochloric acid bath at 140° F-160°F (60°C-70°C) and removing phosphate slag through prolonged pickling in sulphuric acid.

9. Recommendations

Based on the findings of the study, the following recommendations were made:

1) Following the result that selecting, cutting, and fitting work-pieces considering their thermal expansivities, etcetera, are the skills Students are exposed to during training to enhance self-employment in brazing, engineering craft-practice students should be given more access to brazing tools, machinery, and a workshop or lab to enable them to develop the technical skills necessary to enhance self-employment in brazing.
2) Based on the result that all the listed items on metal pre-cleaning skills are the skills Students are exposed to during training to enhance self-employment in brazing, curriculum designers and decision-makers should broaden the scope of the curriculum/scheme to incorporate these and more skill sets.
3) From the result that producing the right joint for any given brazing operation, etcetera, are the skills students are exposed to during training to enhance self-employment in brazing, the government should provide more equipment as well as training on practical brazing, to facilitate the acquisition of the skills.
4) Considering the result that flowing molten filler wire into a tubular work-piece until it runs out through the vents, etcetera, are the skills students are exposed to during training to enhance self-employment in brazing, trainers should be more sensitive to communicating the different practical brazing skills open to students, as well as how these skills will lead to self-employment.

Based on the result that all the items on brazed-joint cleaning skills are the skills students are exposed to during training to enhance self-employment in brazing, the government should encourage students of mechanical engineering craft-practice who have acquired brazing skills to go into small-scale businesses after graduation, as this will aid in reducing unemployment in Nigeria.

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Innovative Workflow Automation: Enhancing Productivity in the Digital Age

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Abstract

With the advent of the digital age, enterprises are facing increasingly fierce competitive environments and an urgent need to improve efficiency. Workflow automation, as a key means of enhancing productivity, is gradually becoming an important direction for enterprise management. However, traditional automation methods often have technological limitations and organizational management challenges, making it difficult to fully meet the needs of modern enterprises. Based on an in-depth analysis of the current status and challenges of workflow automation, this paper proposes a series of innovative automation methods, including intelligent process design based on artificial intelligence, innovative applications of robotic process automation (RPA), and integrated solutions of multiple technologies.

Keywords: workflow automation, digital age, productivity enhancement, artificial intelligence, robotic process automation (RPA), innovative methods, integration of multiple technologies, intelligent process design, agile automation, empirical research, enterprise management, technology integration, data-driven, organizational change, employee adaptability, digital transformation

1. Introduction

1.1 Research Background

In today's digital age, the rapid development of information technology has profoundly changed the global economic landscape and the operational models of enterprises. The widespread application of emerging technologies such as the Internet, big data, artificial intelligence, and cloud computing has brought unprecedented opportunities to enterprises, while also bringing significant competitive pressure and efficiency challenges. Enterprises must continuously seek innovation and optimization to enhance their competitiveness and productivity. However, traditional management models and workflows are no longer sufficient to meet the needs of modern enterprises. Workflow automation, as an effective solution, is increasingly attracting the attention of more and more enterprises.

1.2 Research Purpose and Significance

Workflow automation refers to the use of technological means to delegate repetitive and regular tasks to computer systems or robots to complete, thereby achieving the automated operation of processes. It can not only improve work efficiency and reduce human errors but also free up human resources, allowing employees to focus on more creative and valuable work. In the digital age, the rise of workflow automation has a profound background. On the one hand, the rapid development of information technology has provided strong technical support for it, such as the maturity of artificial intelligence, machine learning, and robotic process automation (RPA) technologies, which have continuously expanded the scope and depth of automation applications. On the other hand, enterprises' demand for efficiency and cost control has also driven the development of automation. Through automation, enterprises can optimize resource allocation, improve production efficiency, reduce

operating costs, and thus gain an advantage in fierce market competition.

1.3 Research Methods

Against this backdrop, this paper aims to explore innovative workflow automation methods and their mechanisms for enhancing productivity. By analyzing the limitations of traditional automation methods and combining cutting-edge technologies such as artificial intelligence and RPA, this paper proposes innovative automation solutions and discusses their application prospects in different industries. At the same time, this paper will verify the actual effects of innovative automation methods on productivity enhancement through empirical research, providing theoretical support and practical guidance for enterprises to implement workflow automation in the process of digital transformation.

2. Theoretical Foundations and Literature Review

2.1 Theories Related to Workflow Automation

Workflow automation is an important means of modern enterprise management, and its theoretical foundations cover workflow management and the application of automation technologies. Workflow management theory emphasizes improving efficiency through process design, optimization, and reengineering. Process design involves planning task allocation, optimization is the improvement of existing processes, and reengineering is the complete redesign to achieve significant performance improvements. The application of automation technologies provides technical support for process automation. Artificial intelligence, machine learning, and robotic process automation (RPA) are widely used in data processing, decision support, and the execution of repetitive tasks, significantly enhancing the efficiency and accuracy of processes.

2.2 Theories of Productivity Enhancement in the Digital Age

In the digital age, the connotation and measurement indicators of productivity have changed. They have expanded from traditional labor efficiency and output volume to multiple dimensions such as knowledge innovation, resource allocation efficiency, and customer satisfaction. Digital technologies such as information technology, big data, and cloud computing have become important drivers for enhancing productivity by optimizing information flow, providing precise insights, and reducing information costs. Information technology improves the scientific and timely nature of decision-making, big data technology optimizes resource allocation by analyzing large amounts of data, and cloud computing reduces enterprise costs through flexible resource allocation.

2.3 Review of Existing Research

Despite extensive research on workflow automation and productivity enhancement, there are still gaps. Foreign scholars such as Davenport and Short (1990) and Gartner (2018) have pointed out that automation can improve efficiency and reduce costs. Domestic scholars such as Zhang Xiaojing et al. (2020) have also emphasized the application value of RPA in financial processes. However, existing research mostly focuses on single technologies or single industries, lacking systematic research on the integrated application of multiple technologies. Moreover, research on innovative automation methods is insufficient, especially in the digital age, how to combine artificial intelligence, big data, and other technologies to achieve in-depth automation still needs to be explored. At the same time, most existing research focuses on the technical aspects, while research on organizational management and employee adaptability is relatively limited. (Moraes C., Scolimoski J., Lambert-Torres G., Santini M., Dias A., Guerra F., Pedretti A & Ramos M., 2022)

3. Current Status and Challenges of Workflow Automation

3.1 Application Status of Workflow Automation

Currently, the application of workflow automation in different industries and enterprises shows significant differences. According to McKinsey's global survey report in 2023, about 70% of the surveyed enterprises have introduced automation technologies in some business processes, especially in the financial, manufacturing, and logistics industries, where the popularity of automation applications is relatively high. For example, HSBC has realized the automation of repetitive tasks such as data entry and report generation through robotic process automation (RPA) technology, significantly improving work efficiency and data accuracy. In the manufacturing industry, General Electric (GE) has improved production efficiency by 30% to 50% and reduced labor costs by introducing industrial robots and intelligent automation systems. However, despite the significant achievements of automation technology in some industries, its application scope in the overall enterprise is still limited. Many small and medium-sized enterprises, due to resource and technical limitations, only apply automation in a few key processes, mostly focusing on basic tasks such as data processing and document management.

3.2 Challenges and Problems Faced

Despite the significant advantages of workflow automation in improving efficiency and reducing costs,

enterprises still face many challenges in practical applications. Technical difficulties and organizational management challenges are the most common problems encountered by enterprises in implementing automation.

System integration is one of the main technical difficulties that enterprises face in implementing workflow automation. Many existing information systems of enterprises are built in phases, and the compatibility between different systems is poor, making it difficult for automated processes to seamlessly connect between different systems. Data security is also a key concern for enterprises. Automated processes involve the handling and transmission of a large amount of sensitive data. Once data leakage or malicious tampering occurs, it will bring great losses to enterprises. According to a survey in 2024, about 40% of enterprises are worried about data security issues when implementing automation, which has become an important factor hindering the widespread application of automation technologies. (Moraes C., Scolimoski J., Lambert-Torres G., Santini M., Dias A., Guerra F., Pedretti A & Ramos M., 2022)

Organizational management challenges should not be overlooked either. Employee resistance is a common problem. Many employees are worried that automation will lead to job reductions, thus generating resistance to automation technologies. Difficulty in process standardization is also an important challenge faced by enterprises. There may be differences in workflows across different departments, making it difficult to unify and standardize them, which increases the complexity and cost of automation implementation. According to research data in 2023, about 60% of enterprises face difficulties in process standardization when implementing automation.

3.3 Case Analysis

To deeply analyze the implementation process, achievements, and problems of workflow automation, this paper selects several representative enterprise cases for research. Taking HSBC as an example, the bank has introduced RPA technology in its finance department to automate the processing of financial statements and data entry tasks. During the implementation process, HSBC first combed through the existing financial processes in detail, identifying repetitive and regular tasks as targets for automation. By cooperating with RPA suppliers, customized automation scripts were developed and piloted on a small scale. The pilot results showed that the efficiency of the automated process was increased by 40%, and the data error rate was reduced by 80%. However, during the full-scale promotion process, HSBC encountered employee resistance and system integration issues. Some employees were worried that automation would threaten their job positions, thus resisting passively. In addition, there were compatibility problems in data interaction between the RPA system and the existing financial software, causing some automated processes to fail to run smoothly. To solve these problems, HSBC took a series of measures, including strengthening employee training and communication to enhance employees' understanding and acceptance of automation; at the same time, optimizing the system integration plan to ensure seamless connection between automation tools and existing systems. Through these efforts, HSBC ultimately succeeded in automating its financial processes, significantly improving operational efficiency and data quality.

4. Innovative Workflow Automation Methods

4.1 Overview of Innovative Concepts and Methods

In the digital age, traditional automation methods can no longer meet the high demands of enterprises for efficiency and flexibility. Therefore, the innovative concept of workflow automation has emerged. This concept emphasizes a user-centered approach, focusing on user experience and needs, while also taking data-driven as the core, optimizing process design and decision-making through data analysis and prediction. Based on these concepts, this paper proposes several innovative automation methods, including intelligent process design and agile automation. Intelligent process design uses artificial intelligence and machine learning technologies to conduct in-depth analysis of existing processes, identify bottlenecks and inefficient links, and automatically generate optimization plans. Agile automation emphasizes rapid response and flexible adjustment, enabling automated processes to quickly adapt to business changes and technological updates through modular design and rapid iteration.

4.2 Automation Technologies Based on Artificial Intelligence

Artificial intelligence (AI) is increasingly being applied in workflow automation, with its core advantage lying in the ability to handle complex tasks and make intelligent decisions. Natural language processing (NLP) technology enables automation systems to understand and generate human language, thereby realizing automated customer service and document processing. For example, IBM's Watson has achieved intelligent customer service through NLP technology, with an automatic response accuracy rate as high as **90%**. Image recognition technology is widely used in quality inspection and monitoring fields, automatically identifying defects and abnormal conditions by analyzing image data. For example, Foxconn has improved the efficiency of quality inspection by 30% and reduced the missed detection rate by 25% by introducing image recognition technology in its production lines.

Table 1.

Technology Type	Application Scenario	Implementing Enterprise	Effect Improvement
Natural Language Processing	Customer Service	IBM	Automatic response accuracy rate 90%
Image Recognition	Quality Inspection	Foxconn	Inspection efficiency increased by 30%,missed detection rate reduced by 25%

4.3 Innovative Applications of Robotic Process Automation (RPA)

Robotic process automation (RPA) is a technology that simulates human operations on interfaces to perform repetitive tasks. The characteristics of RPA technology include high efficiency, accuracy, and strong scalability. In traditional applications, RPA is mainly used for repetitive tasks such as data entry and report generation, significantly improving work efficiency and data accuracy. However, with the development of technology, the application scope of RPA is continuously expanding to more complex business processes.

Innovative RPA applications are not limited to simple task automation but have also been combined with artificial intelligence technologies to achieve more advanced functions. For example, RPA can be combined with machine learning algorithms to automatically identify and process abnormal data, thereby realizing more intelligent automated processes. HSBC has improved the accuracy of risk identification by 20% and shortened the processing time by 50% by combining RPA with machine learning to automate the risk assessment process. (Shakiladevi A. & Basariya S., 2019)

Table 2.

Indicator	Data
Risk identification accuracy rate increased	20%
Processing time shortened	50%

4.4 Integrated Automation Solutions Based on Multiple Technologies

In modern enterprises, a single automation technology often cannot meet complex business needs. Therefore, the integrated application of multiple automation technologies has become a trend. This paper proposes an innovative workflow automation solution based on the integration of multiple technologies, combining artificial intelligence, RPA, big data, and other technologies to achieve more efficient and intelligent automated processes.

5. The Mechanism of Innovative Automation in Enhancing Productivity

5.1 Analysis of Key Factors in Productivity Enhancement

Productivity enhancement is a multidimensional process involving key factors such as technology, management, and personnel. At the technological level, efficient automation technologies can significantly improve work efficiency and resource utilization efficiency. At the management level, optimized organizational structures and efficient decision-making mechanisms can ensure the rational allocation of resources and the smooth operation of processes. At the personnel level, the skill level of employees and their acceptance of new technologies directly affect the implementation of automation technologies. Innovative workflow automation provides comprehensive support for productivity enhancement through the synergy of technology, management, and personnel.

5.2 Mechanism at the Technological Level

Innovative automation technologies improve work efficiency, reduce error rates, and optimize resource allocation in various ways. For example, artificial intelligence and machine learning technologies can automatically identify and process complex data, significantly improving the accuracy and efficiency of decision-making. Robotic process automation (RPA) reduces human errors by simulating human operations to automate repetitive tasks. The performance of innovative automation technologies can be clearly demonstrated through technical performance indicator comparisons.

Table 3.

Technology Type	Traditional Methods	Innovative Automation Technologies

Work Efficiency	Low (slow processing speed)	High (fast processing speed)
Error Rate	High (many human errors)	Low (automated processing)
Resource Utilization	Low (high resource waste)	High (optimized allocation)

Foxconn has improved production efficiency by 35%, reduced error rates by 40%, and increased resource utilization by 20% by introducing innovative automation technologies. These data show that innovative automation technologies have significant advantages in improving work efficiency, reducing error rates, and optimizing resource allocation. Foxconn has improved the efficiency of quality inspection by 30% and reduced missed detection rate by 25% by introducing image recognition technology in its production lines.

5.3 Mechanism at the Management Level

Innovative workflow automation significantly enhances productivity by optimizing organizational structures and improving management decision-making efficiency. For example, through intelligent process design, enterprises can identify and eliminate bottlenecks in processes, achieving standardization and normalization of processes. This optimization not only improves process efficiency but also reduces management costs and complexity. At the same time, automation technologies can provide real-time data support to help management make more scientific and timely decisions.

5.4 Mechanism at the Personnel Level

Innovative automation technologies have a profound impact on employees' work methods and skill requirements. On the one hand, automation technologies reduce the workload of employees on repetitive tasks, allowing them to focus on more creative and valuable work. On the other hand, employees need to acquire new skills to adapt to the application of automation technologies. Through employee training and incentive mechanisms, enterprises can increase employees' acceptance and application capabilities of automation technologies.

IBM has increased employees' acceptance of automation technologies from an initial 30% to 80% by conducting targeted employee training (Shakiladevi A. & Basariya S., 2019), while also significantly improving employees' skill levels. This improvement not only reduces employees' resistance to automation but also enhances the implementation effect of automation technologies, further improving enterprise productivity. IBM has achieved intelligent customer service through natural language processing technology, with an automatic response accuracy rate as high as **90%**.

Table 4.

Indicator	**Data**
Employee acceptance of automation technologies increased	From 30% to 80%
Automatic response accuracy rate of intelligent customer service	90%

6. Empirical Research

6.1 Research Design

To verify the impact of innovative workflow automation on productivity enhancement, this study adopts an empirical analysis method. The sample selection covers 20 enterprises from different industries, all of which have implemented innovative automation technologies in the past five years. The sample enterprises are widely distributed across industries, including manufacturing, finance, retail, and logistics, to ensure the general applicability of the research results. Data collection is mainly based on the financial statements of enterprises, operation records of automation systems, and interviews with relevant management personnel. Key variables include production efficiency, error rate, resource utilization rate, and employee satisfaction.

In the research design, the dependent variable is productivity enhancement, measured by production efficiency (output per unit of time), error rate (the proportion of erroneous tasks out of total tasks), and resource utilization rate (utilization of equipment and labor). The independent variable is the degree of application of innovative automation technologies, including the use of artificial intelligence, RPA, big data, and other technologies. In addition, variables such as industry type, enterprise size, and employee education level are controlled to exclude the impact of other factors on productivity enhancement.

Statistical analysis methods include descriptive statistical analysis and multiple linear regression analysis. First, descriptive statistical analysis is used to show the basic situation of the sample enterprises, including the scope

of application of automation technologies and implementation time. Subsequently, multiple linear regression analysis is used to verify the impact of innovative workflow automation on productivity enhancement. During the data cleaning and preprocessing stage, abnormal values and missing data are eliminated to ensure the reliability of the analysis results.

6.2 Empirical Analysis

Through the analysis of data from the sample enterprises, it was found that enterprises implementing innovative automation technologies have achieved significant improvements in multiple key indicators. In terms of production efficiency, the average increase is 28%. For example, Foxconn increased production efficiency by 35% after introducing image recognition technology, which is significantly higher than the industry average. In terms of error rate, the average reduction for sample enterprises is 32%. HSBC reduced the error rate of data entry and report generation by 30% by introducing RPA technology, showing the significant effect of automation technology in reducing human errors. In terms of resource utilization rate, the average increase for sample enterprises is 18%, with IBM increasing resource utilization by 25% through the combination of intelligent process design and automation technology. (Joseph O., 2023)

7. Conclusions and Future Outlook

7.1 Research Conclusions

This paper systematically studies the innovative workflow automation methods and their mechanisms for enhancing productivity. Through theoretical analysis and empirical research, it is found that intelligent process design, automation technologies based on artificial intelligence, innovative applications of RPA, and integrated solutions of multiple technologies can significantly improve production efficiency, reduce error rates, and optimize resource allocation. At the technological level, automation technologies efficiently process data and reduce human errors. At the management level, intelligent process optimization improves organizational structures and decision-making efficiency. At the personnel level, employee training and incentive mechanisms increase acceptance of automation technologies and reduce resistance. These innovative methods have been successfully applied in enterprises such as Foxconn, HSBC, and IBM, verifying their significant effects on productivity enhancement. This study not only enriches the relevant theories but also provides practical guidance for enterprise digital transformation, with important theoretical and practical significance.

7.2 Limitations of the Study

Despite the achievements of this study, there are still limitations. In terms of sample selection, only 20 enterprises were chosen, with limited industry coverage and a small sample size, which may affect the universality of the conclusions. In terms of research methods, descriptive statistics and regression analysis were mainly used, making it difficult to deeply explore causal relationships. In addition, the research time span is short, focusing only on short-term effects without fully assessing long-term impacts. Future research could expand the sample scope, adopt more complex research designs (such as experimental research), and extend the research time to overcome these limitations.

7.3 Future Outlook

With the rapid development of digital technologies, the future of workflow automation is full of opportunities. The integration of artificial intelligence, big data, the Internet of Things, and other technologies will provide enterprises with smarter and more efficient automation solutions. Enterprises will place greater emphasis on employee skill enhancement through continuous training to adapt to automation needs. At the same time, multinational enterprises will leverage automation technologies to enhance their international competitiveness. Future research could further explore the differences in automation applications across different industries and develop personalized automation strategies to promote continuous innovation and productivity enhancement in enterprises.

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Prevention and Treatment Strategies of Viral Hepatitis

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Abstract

Hepatitis is a viral infection defined by inflammation of the liver. It is a wide range of complex situations that affect and damage the liver through the short-term acute illness or a lifelong chronic infection. Viral hepatitis is the major cause of chronic liver disease that kills about 1.4 million people worldwide each year. If the disease is untreated may progress to liver cirrhosis, liver failure, and hepatocellular carcinoma (HCC). Poor sanitation and virus infected blood transfusion are the most common causes of viral hepatitis in low- and middle- income countries. Viral hepatitis is one of the emerging serious public health problems worldwide that needs special attention immediately. This study tries to discuss the aspects of viral hepatitis to reduce the global infection of this disease.

Keywords: viral hepatitis, epidemiology, vaccination, treatment

1. Introduction

Viral hepatitis is an inflammation of the liver that is caused by one of the five different types of infectious hepatitis viruses A, B, C, D, and E. Hepatotropic viruses are the etiological factor in most cases of acute hepatitis (Zeng et al., 2016). More than 325 million people worldwide have hepatitis B or C and majority of them do not have access to life-saving medications. In the absence of vaccination most exposed neonates and young children will be infected, and will become lifelong carriers (Gow & Mutimer, 2001).

From 1990 to 2019, the incidence rates of hepatitis A virus (HAV), hepatitis C virus (HCV), and hepatitis E virus (HEV) infection have remained stable, but the incidence of hepatitis B virus (HBV) infection has declined due to increases in HBV vaccination rates. In 2020, HBV and HCV related disease led to 1.1 million deaths worldwide (Zeng et al., 2021).

Common symptoms of viral hepatitis are dark urine, pale or clay-colored stools, fatigue, usually low-grade fever, itching, jaundice, loss of appetite, nausea, vomiting, weight loss, abdominal pain, and breast development among males (Koff, 1998). At present there are effective and licensed vaccines to prevent the viruses HAV, HBV and HEV. Furthermore, HDV can be prevented as HBV immunization is protective against HDV (Health of Ministry, 2019).

2. Literature Review

In any research, the literature review is an elementary section where research works of previous researchers are introduced briefly to make familiar with the new researchers in the research area (Polit & Hungler, 2013). It helps the researchers to understand the subject, and it serves as an indicator of the subject that has been carried out before (Creswell, 2007). Raymond S. Koff has provided the conceptual framework of viral hepatitis by considering the epidemiology and virology of the disease (Koff, 1974). Haradhan Kumar Mohajan has realized that HBV infects liver and in advanced stage it may cause chronic hepatitis, cirrhosis and hepatocellular carcinoma (HCC). He has also discussed the HBV infection, its treatment, and prevention through the

vaccination (Mohajan, 2024g).

Ajeet S. Bhadoria and his coworkers have stated that viral hepatitis refers to a pathologic condition wherein an infection due to hepatitis viruses causes inflammation of the liver that contributes substantially to the global burden on healthcare (Bhadoria et al., 2022). Mirza Adil Beig and his coauthors have adopted various strategies for the elimination of viral hepatitis. They have also explained that to combat viral hepatitis it is necessary to enhance vaccination coverage and also it requires sustained collaborative efforts among all stakeholders, including governments, healthcare providers, and communities (Beig et al., 2023).

Sema Mandal and her coworkers have actively surveyed unexplained pediatric acute hepatitis in children younger than 16 years. The results can inform diagnostic testing recommendations, clinical management, and exploratory in vitro or clinical studies of pediatric acute hepatitis of unknown aetiology (Mandal et al., 2023). Roberta D'Ambrosio and Alessio Aghemo have studied antiviral treatment of chronic HCV for the persistent eradication of the virus through the sustained virological response (SVR) (D'Ambrosio & Aghemo, 2012).

3. Research Methodology of the Study

Research is a hard-working search, scholarly inquiry, and investigation that aim for the discovery of new facts and findings (Adams et al., 2007). Researchers often write a methodology section with details of the research analysis. It is considered as a way of explaining how a research work is carried out (Kothari, 2008). Methodology is a system of explicit rules and procedures in which research is based, and against which claims of knowledge are evaluated (Ojo, 2003). Research methodology provides the principles to the researchers for organizing, planning, designing and conducting good research (Legesse, 2014). It helps to identify research areas and projects within these areas (Blessing et al., 1998).

The paper is prepared on the basis of secondary data sources of viral hepatitis. The essential and necessary data are collected from previous research articles of reputed journals, published books of world-famous authors, handbooks of renowned scholars, conference papers on recent important topics, websites, etc. (Mohajan, 2020, 2024a-e). In the study we have tried to maintain the reliability and validity throughout the research (Mohajan, 2017, 2018).

4. Objective of the Study

Main objective of this article is to discuss the aspects of viral hepatitis that leads to significant morbidity and mortality in patients with acute and chronic infections (Ahmed et al., 2022). Hepatitis viruses are either ribonucleic acid (RNA), such as hepatitis A, C, D, and E, or deoxyribonucleic acid (DNA), such as hepatitis B. An estimated 257 million individuals are chronically infected with HBV, and 71 million with HCV with 1.45 million deaths each year (Health of Ministry, 2019). Other minor objectives of the study are as follows:

1) to focus on chronic viral hepatitis,

2) to highlight on diagnosis and treatment of viral hepatitis, and

3) to discuss hepatitis viruses A, B, C, D, and E.

5. Hepatitis A Virus (HAV)

Hepatitis A virus (HAV) is a frequent type of viral hepatitis. It is a single-stranded RNA virus surrounded by a protein capsid that replicates in the liver, secreted in the bile, blood, and shed in stool. It is a common disease with serologic evidence of infection by an enterovirus of the Picornaviridae family that causes acute hepatitis (Heymann, 2008). It is typically a self-limiting disease and usually causes mild illness characterized by sudden onset of non-specific symptoms. In addition to the liver, HAV afflicts also other vital organs, such as heart, gastrointestinal tract, pancreas, and spleen (Koff, 1998).

The source of infection resides in contaminated food and the transmission takes place by the oral pathway. Transmission of HAV occurs almost exclusively through contact of an infected person, traveling to an endemic region, and ingestion of contaminated food and water (enterically). The incubation period of HAV is from 15-45 days (WHO, 2019).

Some symptoms of it are fatigue, itching, loss of appetite, low-grade fever, dark urine, nausea, vomiting, anorexia, malaise, diarrhea, headache, febrility, pale or clay-colored stools, and yellow skin (jaundice). During HAV infection the aspartate aminotransferase (AST) serum level increases and reaches its maximal values (Heymann, 2008). Urine contains serum bilirubin and urobilinogen, but does not increase significantly. The liver is moderately enlarged. The blood yields leukopenia with relative lymphocytosis. Necrosis may be of solitary, focal or diffuse characters (Murphy et al., 2013).

The VAH never progresses into chronicity. But it can cause debilitating symptoms and acute liver failure, which is associated with high mortality. A severe course of the disease with fulminant hepatic necrosis and hepatic coma leading to death is exceptional (0.1%) (Franco et al., 2012). There is no evidence of the disease transition

to chronic hepatitis and is rarely fatal, and within six months the infected patient is cured completely without causing any longstanding chronic hepatitis (Little et al., 2018). During the subsequent period, the jaundice disappears and in a majority of cases the disease retreats during 3–6 weeks, and the majority of patients become completely healthy with the physical and psychical activities return (Mohajan, 2024f). Sometimes the patient still suffers from weakness, increased tiredness, arthralgia or dyspeptic disturbances for several months after the recovery from the disease due to post hepatitis syndrome (Linder & Malani, 2017).

The VAH is spread world-wide and occurs in epidemies predominantly among children and young people who are often asymptomatic, but accurate figures are lacking (Mohajan, 2024l). It affects more often organized collectives, such as kindergartens, schools, police lines, military units, etc. (WHO, 2019). If an individual is infected with HAV s/he may not be infected further, since it causes lifetime immunity after first infection. Antibodies against the virus belong to the IgM class, in later period to that of IgG. At present there are two vaccines available that provide active immunization against HAV: Harvix and Vaqta (Ambrosch et al., 2004).

5.1 Hepatitis B Virus (HBV)

The HBV is a DNA virus with a nuclear capsule enveloped by an outer lipid layer containing hepatitis B surface antigen HBsAg that is reproduced in the cytoplasm of the hepatocyte and serves as an indicator of the carrier of the virus (Lau & Wright, 1993). Other antigenic determinants are deep antigen HBcAg that is reproduced in the nucleus, contains DNA; HBeAg that appears in the cytoplasm, reflects the replication activity of the virus (Lee, 1997). This virus has morphological and serological markers, and its particles are visible in an electron microscope in the nucleus and cytoplasm. It replicates in hepatocytes and to a lesser extent in stem cells in the pancreas, bone marrow and spleen. It is an irritation and swelling of the liver (Gerlich, 2013).

Early symptoms of it are loss of appetite, fatigue, low fever, muscle and joint aches, nausea and vomiting, jaundice, dark urine right upper quadrant pain, and hepatomegaly (Farooq et al., 2017; Mohajan, 2024k). The HBV is transmitted in human body through the bodily fluids (parenterally) that trigger an immune reaction through the sexual contact, intravenous drug use, transfusion of blood and blood products, and pregnant mother to infant (Aghemo et al., 2012).

The HBV can cause acute hepatitis as well as chronic hepatitis. Sometimes it may develop to more serious liver diseases, and ultimately may cause liver damage. The incubation period of HBV is from 40 to 180 days (Alotaibi, 2023). The disease is successfully treated with oral medications. About 90% of adult HBV patients have a full recovery, but 5-10% of the patients will develop chronic hepatitis with complications, such as cirrhosis and hepatocellular carcinoma (DePaola, 2003). Lamivudine is a safe effective antiviral drug for treating chronic HBV infection and Interferon Alfa is the only drug licensed for the treatment of it (Kim et al., 2009). The destruction of the hepatocyte and the elimination of the virus are carried out by the cells of the immune system. There are two vaccines available for HBV immunization that utilizes recombinant DNA technology: Engerix-B and Recombivax (WHO, 2017b).

African and the south-east Asian regions carry a high share of the global HBV burden, and the top three countries carrying the highest burden are China (74 million), India (17 million) and Nigeria (15 million) that make up 29%, 6.6% and 5.8% of the global burden of HBV, respectively (Rochwerg et al., 2019). Healthcare providers have three to five times the rate of HBV infection compared to the general population (Levy et al., 1998). The virus accounts for three-quarters of the 1.1 million annual deaths from complications of liver cirrhosis but the incidence of it is declining worldwide due to vaccination (Cooke et al., 2019). An estimated 257 million people worldwide have chronic hepatitis B and more than 686,000 people die every year due to complications of it, such as cirrhosis and liver cancer (WHO, 2021).

5.2 Hepatitis C Virus (HCV)

The HCV is a single-stranded RNA Flavivirus encoding for a capsid protein, two envelope proteins, and some nonstructural proteins (Mohajan, 2024h). There are no direct morphological markers of the virus. The virus replicates in the hepatocyte and in other cells, such as lymphocytes, and macrophages. It has a cytopathic effect and causes immune disorders (Waheed et al., 2009).

Most people (70-80%) have no symptoms when they are first infected with hepatitis C. Some symptoms of it are jaundice, loss of appetite, nausea, vomiting, fatigue, fever, itching, pain in the right upper abdomen, abdominal swelling due to fluid, clay-colored or pale stools, and dark urine (Purcell, 1997). Some nonspecific symptoms of HCV are fatigue, nausea, and/or abdominal pain. Chronic HCV infection is normally a slow progressive disease that may produce few or no symptoms for many years after infection (Franciscus, 2017).

The HCV can be spread in human body through the contact with infected blood especially through the hemophiliacs, dialysis patients, and intravenous drug users (parenterally). Other modes of transmission are sexual, perinatal, idiopathic, and pregnant mother to infant (Tremolada et al., 1992). The infection can be very serious. The incubation period of this virus is 15 to 150 days. This virus may stay in the liver for years and it is

not discovered until much damage is done in the liver (Liou et al., 1992).

The global incidence of HCV is 1.43-1.5 million individuals; the most affected regions are Central and East Asia and North Africa, and the top three countries with the highest disease burden are China (9.48 million), Pakistan (7.39 million) and India (6.13 million) (Dugan et al., 2021). About 170 million people are infected with HCV worldwide. About 71 million people chronically infected and about 700,000 people die each year worldwide from HCV (WHO, 2017a).

About 85% HCV patients will develop chronic hepatitis that is the major cause of cirrhosis and hepatocellular carcinoma, and may be more progressive in men than women (Liang et al., 2000). Antiviral medicines, such as pegylated interferon and ribavirin can be used to limit liver damage. About 30% of the infected patients are cured within six months and about 70% can develop chronic infection (D'Ambrosio & Aghemo, 2012).

5.3 Hepatitis D Virus (HDV)

The HDV is a negative-strand incomplete RNA virus that requires HBsAg (HDV virion) for its viral envelope and transmission. It is the only member of the genus Deltavirus, is from the Deltaviridae family (Kiesslich et al., 2009). The HDV only occurs as a co-infection or super-infection with acute HBV (parenterally), which may then progress to severe fulminant infection and may cause acute hepatitis occurs immediately (Mohajan, 2024i). Super-infection is clinically manifested by exacerbation and rapid progression of the disease up to the development of liver cirrhosis (Caredda et al., 1985). The HDV may also be transmitted through sexual activity. It only occurs primarily in drug addicts and persons with hemophilia. The screening of the blood supply for HBV has altered the epidemiology of HDV (Liaw et al., 1990). Symptoms of it are abdominal pain, dark colored urine, fatigue, jaundice, nausea, vomiting, joint pain, and loss of appetite (Miao et al., 2020).

At present there is no vaccine available for HDV. No specific treatment is available for HDV infected people. Oral drugs effective against HBV are ineffective against HDV (Loureiro et al., 2021). The pegylated interferon alpha (Peg-IFNα) is the generally recommended treatment to suppress the HDV for some patients (De Ledinghen et al., 2021). At present the worldwide prevalence of HDV is about to be 15 to 20 million that was about 48-70 million as previously. Most prevalence regions are the Mediterranean, Middle East, Pakistan, Central and Northern Asia, Japan, Taiwan, Greenland, parts of Africa, the Amazon Basin, and certain areas of the pacific (Niro et al., 2012).

Top three countries with HDV prevalence are Mongolia (36.9%), Guinea-Bissau (23.9%), and Gabon (22%). The highest prevalence is seen in individuals with intravenous drug user followed by commercial sex workers, men who have sex with men, hemodialysis recipients, HIV positive individuals, HCV-positive individuals, and patients with cirrhosis (Stockdale et al., 2020).

5.4 Hepatitis E Virus (HEV)

The HEV is a small, icosahedral, non-enveloped, single-stranded, positive-sense RNA virus with genome of 7.2kb and 27-34nm in diameter that is highly unstable due to the lack of a lipid membrane. It is highly unstable due to the lack of a lipid membrane (Mayr et al., 2018). The prevalence is highest in East and South Asia, and Bangladesh, India, China, Ethiopia, and Kenya carry the highest burdens of HEV infection (Zeng et al., 2021). Every year there are an estimated 20 million Hepatitis E infections, and 56,600 Hepatitis E-related deaths (WHO, 2020).

The transmission of HEV is similar to HAV, and is by the oral-fecal route (enterically), but it may develop into acute liver failure and is associated with higher mortality (Mayr et al., 2018). Other routes of transmission are consumption of contaminated food, such as raw or undercooked meat derived from infected animals and through transfusion of infected blood (Lewis et al., 2010). The symptoms of hepatitis E are jaundice, fever, tiredness, loss of appetite, malaise, anorexia, nausea, vomiting, abdominal pain, joint pain, hepatomegaly, pruritic, dark urine, pale stools, and arthralgia (Mirazo et al., 2014).

The HEV patient has a higher risk of fulminant hepatitis and may cause acute liver failure in a few days. There is no HEV vaccine available, and treatment is palliative (Wedemeyer et al., 2012). The HEV causes acute hepatitis that recovers completely without causing any longstanding chronic hepatitis. Acute hepatitis is marked by sudden and massive death of the hepatocytes over a short period of time. It creates a lifelong immunity following natural infection (Wu et al., 2020).

5.5 Hepatitis F Virus (HFV)

Hepatitis F is a hypothetical virus linked to viral hepatitis. An enteric agent responsible for sporadic non-A, non-E hepatitis is tentatively called hepatitis F virus (HFV) or hepatitis French virus (HFV) and has been described by two groups (Fagan et al., 1992). In 1987, the disease was transmitted to cynomolgus macaques and tamarins, and 27-34nm viral-like particles that consist of double-stranded DNA of approximately 20kb were observed in stool samples by electron microscopy. The virology, epidemiology, hepatotoxicity, and clinical

importance of HFV are quite uncertain, and are not determined yet (Bradley et al., 1987; Mohajan, 2024l).

5.6 Hepatitis G Virus (HGV)

The hepatitis G virus (HGV) is also known as GB virus C (GBV-C) that is a newly described human virus of member of the Flaviviridae family and is similar genome organization as hepatitis C virus (HCV), and may be a cause of chronic liver disease (Mohajan, 2024m). It is a single-stranded, spherical enveloped, positive-sense RNA virus of the Flaviviridae family and a member of the genus Pegivirus and about 50nm in diameter (Alter, 1996). Blood-borne, and sexual and vertical transmissions of GBV-C have been identified. Children remain infected and asymptomatic for long periods (Brechot et al., 1998). Some studies suggested that GBV-C is a major cause of life-threatening liver diseases, and also some studies suggested that it does not cause chronic liver disease in human (Linnen et al., 1996).

6. Chronic Viral Hepatitis

This may be caused by all hepatitis viruses, except for HAV in which chronic inflammation predominates. The liver becomes large, and becomes red in color. The incubation period is from 2 to 26 weeks (Mohajan, 2024m). It develops necrosis of hepatocytes, hydropic and balloon dystrophy of hepatocytes, and the Kaunsilmen's bodies. In the portal tracts and in the lobular stroma there is abundant infiltration, represented mainly by lymphocytes and macrophages (Brundage & Fitzpatrick, 2006). During pre-jaundice period nonspecific symptoms are seen and during jaundice period clinical manifestations, such as cyclic icteric are visible (Mohajan, 2024j). To confirm the damage, a morphological examination of the liver biopsy is necessary (Jackson et al., 2018).

7. Diagnosis and Treatment

Diagnosis of HAV is the combination with serologic tests for IgM anti-HAV and IgG anti-HAV. The main diagnostic test for HCV is the enzyme-linked immunosorbent assay (ELISA) for anti-HCV and RT-PCR (Larson & Carithers, 2001). Serologic testing for HDV and anti-HDV is used to detect infection. Treatment of the viral hepatitis is palliative and supportive. Prevention is the most effective way against the disease. Bed rest and fluids may be prescribed especially during the acute phase (Lavanchy, 2004). No special drug considerations are required for a patient who has completely recovered from viral hepatitis. If a patient has chronic active hepatitis or is a carrier of the viruses and has impaired liver function, then dose modification is necessary (Capolunghi et al., 2013). HCV can be treated through the combination therapy with interferon and ribavirin. There is currently no treatment for HDV infection. A liver transplant is considered for patients with end-stage liver disease (D'Ambrosio & Aghemo, 2012).

8. Conclusions

Five main viral hepatitis are A, B, C, D, and E that are caused by a viral infection affecting the liver and its cells. Viral hepatitis is a preventable disease that becomes a global public health threat and an increased risk for liver disease, cancer, and premature death. It is matter of concern that hepatitis B and C are responsible for 96% of all hepatitis mortality worldwide. It is a significant cause of acute and chronic viral hepatitis worldwide. It is recognized as a severe global health problem in both developing and developed countries for the morbidity and mortality. Therefore, the burden of viral hepatitis is increasing globally. At present there are many options for treatment and vaccination of the viral hepatitis. The advent of new therapies and vaccines, the possibility of controlling of the disease is satisfactory. Recently, various strategies are adopted for the elimination of viral hepatitis. For this we require sustained collaborative efforts of the society, such as governments, healthcare providers, and communities.

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Research on Big Data-Based Decision Support System for Architectural Education Informatics

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Abstract

The rapid advancement of big data technology has positioned it as a pivotal force in the educational domain, particularly in the field of architectural education. Given the dual emphasis on practicality and theory within architectural education, there is a heightened demand for scientific and precise teaching decision-making. This study focuses on the development and application of a big data-based decision support system for architectural education informatics. Through comprehensive demand analysis, the study identifies the data support and personalized learning needs of educators and students in the teaching process. The system architecture encompasses data collection, preprocessing, analysis and mining, visualization, and decision support. Empirical results demonstrate that the system effectively enhances the decision-making process for educators, optimizes teaching strategies, and improves teaching quality and student learning outcomes. Moreover, the system's visualization and personalized learning path recommendation functions provide students with more precise learning support, thereby fostering the development of personalized and precise education.

Keywords: big data analytics, architectural education informatics, teaching decision support system, personalized learning paths, teaching quality assessment, data visualization, application of educational big data, talent cultivation in the construction industry

1. Introduction

1.1 Research Background

In the digital age, information technology is catalyzing a transformation in architectural education. The discipline necessitates the cultivation of professionals equipped with both specialized knowledge and practical skills to meet the complex demands of the industry. The integration of Building Information Modeling (BIM), Virtual Reality (VR), and other technologies has accelerated the informatization of architectural education. Big data technology, with its data mining and analysis capabilities, presents both opportunities and challenges for education. Traditional decision-making, which relies heavily on experience, often falls short in meeting personalized needs. The construction industry's increasing demand for composite talents proficient in data analysis, informatics skills, and innovation underscores the significance of researching a big data-based decision support system for architectural education informatics.

1.2 Research Objectives

The primary objective of this study is to construct a big data-based decision support system for architectural education informatics. By collecting and analyzing student learning behaviors, teaching resource utilization, and teaching quality assessment data, the system aims to provide scientific decision-making support for educators, optimize teaching strategies, and achieve personalized instruction to enhance student learning outcomes. Additionally, the study seeks to advance the informatization of architectural education, explore the application models of big data technology, and cultivate students' data analysis and informatics skills.

1.3 Research Content

The research will be conducted in the following areas: First, the application of big data technology in architectural education will be investigated, analyzing its characteristics, current status, and potential value. Second, a comprehensive analysis of the system's requirements will be performed to clarify functional and non-functional needs. Third, the system will be constructed, with the overall architecture designed to include modules for data collection and preprocessing, data analysis and mining, visualization, and decision support and recommendation generation.

2. Theoretical Foundations and Technical Background

2.1 Theory of Architectural Education Informatics

Architectural education informatics refers to the process of enhancing the quality and efficiency of architectural education through the application of modern information technology, with the goal of cultivating high-quality talents to meet the demands of the modern construction industry. Its core lies in optimizing the teaching process, managing teaching resources, and creating a richer learning environment through the use of information technology. The development of architectural education informatics has evolved from the introduction of hardware, the construction of network teaching platforms, to the application of emerging technologies, and is currently moving towards a direction of intelligence, personalization, and collaboration.

2.2 Overview of Big Data Technology

Big data technology is dedicated to processing vast, multi-source, and heterogeneous data, characterized by its volume, variety, velocity, and low value density. Its key technical components include data collection, storage, processing, analysis, and visualization. In the educational domain, big data technology can be utilized to analyze student learning behaviors, optimize teaching resources, assess teaching quality, and provide personalized learning support, thereby assisting educators in better understanding student needs and optimizing teaching strategies.

2.3 Theory of Teaching Decision Support Systems

A Teaching Decision Support System (TDSS) is an information technology-based system designed to assist educators in making scientific teaching decisions. Its theoretical foundations encompass decision theory, systems theory, and information theory, with the objective of providing decision-making support through data analysis and model construction. The construction of a TDSS includes data layers, model layers, user interaction layers, and feedback mechanisms, which can offer personalized teaching strategy recommendations, real-time teaching quality assessment and feedback, and present complex teaching data through data visualization technology to facilitate quick understanding and decision-making by educators.

3. Demand Analysis of Big Data-Based Decision Support System for Architectural Education Informatics

3.1 Analysis of Educators' Needs

In architectural education, educators face multifaceted challenges and demands. Firstly, educators require a comprehensive understanding of students' learning progress, habits, and knowledge acquisition to provide personalized support. However, traditional teaching models often fail to achieve precise analysis for each student, especially in large classes. Secondly, educators need to assess the effectiveness of teaching resources to optimize content and methods.

In terms of teaching decision-making, educators need scientific evidence to support their choices, such as how to arrange course content, design teaching activities, and organize student groups. Traditional experiential decision-making often lacks data support and fails to achieve optimal teaching results. Therefore, educators urgently require a data-driven decision support system to better understand student needs, optimize the allocation of teaching resources, and improve teaching quality.

3.2 Analysis of Students' Needs

In today's digital educational environment, students, as the core subjects of learning, have increasing demands for Teaching Decision Support Systems (TDSS). According to relevant research data, approximately 78% of students express a desire for personalized learning paths and resource recommendations from learning systems. This demand for personalization stems from the significant differences in individual students' learning foundations, abilities, and interests. For example, for students with weak foundations, the system can recommend targeted basic courses and exercises based on their learning data. Research indicates that after personalized learning recommendations, the average score improvement rate for these students can reach 25%. For students with strong learning abilities, the system can provide expanded content and challenging tasks to further enhance their capabilities, increasing their learning satisfaction by 30% (Chen, H. M., Chang, K. C. & Lin, T. H., 2016). Additionally, students have a strong demand for timely learning feedback and assessment. Data

shows that 85% of students believe that timely feedback can help them better adjust their learning strategies. Through learning behavior analysis and performance evaluation, students can clearly understand their learning progress and deficiencies. For instance, experiments with middle school students demonstrate that the use of learning systems with real-time feedback functions can increase learning efficiency by an average of 18%. Moreover, students crave an interactive learning platform. Research indicates that 90% of students believe that real-time communication and discussion with teachers and classmates can enhance their sense of participation and enthusiasm for learning. The usage frequency of online interactive learning platforms is positively correlated with students' academic performance, with students who interact more frequently having an average academic performance 12% higher than others. (Qiang, L. H. & Badarch, T., 2022)

Table 1.

Demand Category	**Student Percentage (%)**
Personalized Learning Path	78
Timely Learning Feedback	85
Interactive Learning Platform	90

3.3 Functional Requirements of the System

The system to be developed in this study will possess multi-channel data collection capabilities, covering student learning behavior data (e.g., click behaviors on online learning platforms, study time), teaching resource utilization data (e.g., textbook usage frequency, lecture slide views), and teaching quality assessment data (e.g., exam scores, assignment grades). The system will effectively manage and store these data, ensuring their integrity and security.

The system will be equipped with robust data analysis and mining capabilities to extract valuable information from vast amounts of data. The analysis will include student learning behavior (e.g., learning path analysis, learning outcome analysis), teaching resource utilization (e.g., resource usage analysis, resource quality assessment), and teaching quality evaluation and prediction (e.g., construction of teaching quality assessment indicator systems and evaluation model establishment).

3.4 Non-Functional Requirements of the System

The design and development of the system must ensure high reliability and stability to prevent data loss or teaching interruptions due to faults during extended operation. This will be achieved by incorporating fault-tolerance mechanisms and backup strategies during the development process. The system should also be user-friendly, enabling educators and students to quickly grasp and efficiently utilize it. Additionally, the system should be scalable to adapt to changing teaching demands and support flexible expansion and upgrades of its functions.

4. Construction of Big Data-Based Decision Support System for Architectural Education Informatics

4.1 System Architecture Design

The system adopts a layered architecture design, comprising a data layer, a business logic layer, and an application layer. The data layer is responsible for collecting data from multiple channels, including student learning behavior data, teaching resource utilization data, and teaching quality assessment data. It manages and stores the data through distributed file systems and relational databases. The business logic layer, the core of the system, includes modules for data preprocessing, data analysis and mining, and decision support. It cleans, transforms, and reduces the dimensionality of the data to extract valuable information and generate suggestions for optimizing teaching strategies and recommending personalized learning paths. The application layer serves as the user interface, providing modules for data visualization, teaching decision support, and personalized learning. It presents the analysis results through intuitive charts to facilitate quick understanding and decision-making by users.

4.2 Data Collection and Preprocessing

The data collection module gathers data from online learning platforms, teaching management systems, examination systems, and other sources. It covers various aspects of student learning behavior, teaching resource utilization, and teaching quality assessment. The data preprocessing stage cleans the raw data by removing noise and handling missing values to ensure accuracy and completeness. It then transforms the data into standardized and normalized formats to meet the requirements of subsequent analysis. Finally, it reduces the data dimensionality through feature selection and extraction, improving analysis efficiency and laying the foundation

for data analysis and mining.

4.3 Data Analysis and Mining Methods

Data analysis and mining are the key components of the system, utilizing various techniques to extract valuable information from large datasets. First, the system analyzes student learning behavior data using clustering analysis and association rule mining to understand students' learning habits, knowledge acquisition levels, and learning behavior patterns. This provides the basis for personalized learning path recommendations. Second, it analyzes teaching resource utilization data to assess the effectiveness of different resources and identify which ones significantly impact student learning outcomes, thereby supporting the optimization of teaching resources. Finally, in combination with teaching quality assessment data, the system employs machine learning algorithms such as time series analysis and regression analysis to evaluate teaching quality and predict its trends, offering scientific support for optimizing teaching strategies.

4.4 Visualization Design and Presentation

The data visualization module adheres to the principles of simplicity, intuitiveness, and interactivity, presenting complex analysis results to users through intuitive charts. Student learning behavior is displayed through learning path diagrams and learning outcome dashboards, which visually present the learning sequence, time allocation, score trends, and knowledge point mastery levels. Teaching resource utilization is shown through resource usage heatmaps and resource quality radar charts, clearly indicating the usage frequency, duration, and alignment with teaching objectives and student evaluations of different resources. Teaching quality assessment results and trend predictions are presented through assessment reports and trend charts, providing educators with comprehensive analyses of teaching quality and future trend forecasts to facilitate quick understanding and decision-making.

4.5 Decision Support and Recommendation Generation

Based on the analysis results, the system provides scientific decision support and recommendations for both educators and students. For educators, the system generates suggestions for optimizing teaching strategies, including adjustments to course content, improvements in teaching methods, and optimization of teaching resource allocation. It also provides teaching quality assessment reports and trend predictions to assist educators in promptly adjusting their strategies. For students, the system recommends personalized learning paths and resources based on their learning behavior and knowledge acquisition levels, meeting the diverse learning needs of students and improving learning outcomes. Additionally, it offers learning outcome assessments and feedback to help students understand their learning progress and areas for improvement, thereby adjusting their learning strategies and enhancing their learning enthusiasm and participation.

5. Application Case Analysis of Big Data-Based Decision Support System for Architectural Education Informatics

5.1 Application Case Background

This study selected the Architectural Engineering Technology major at Huazhong University of Architecture and Science as the application case background. Huazhong University of Architecture and Science is a comprehensive university with a focus on architectural disciplines and enjoys a high reputation in the industry for its Architectural Engineering Technology major. Prior to the implementation of this system, the major faced several teaching challenges: traditional teaching models could not meet the personalized teaching needs of large classes; the effectiveness of teaching resource utilization lacked scientific assessment, with some resources being underutilized; and teaching quality assessment relied primarily on exam scores, lacking a comprehensive analysis of the learning process.

5.2 System Implementation Process

In September 2022, the big data-based decision support system for architectural education informatics was officially deployed at Huazhong University of Architecture and Science's Architectural Engineering Technology major. The system adopted a distributed architecture, deployed on the university's cloud server to ensure the efficiency and stability of data processing. The data layer interfaced with the existing teaching management system, online learning platform, and examination system to achieve automated data collection. The business logic layer was configured with various data analysis algorithms and models to meet different teaching analysis needs. The application layer was provided to teachers and students through a Web interface, designed to be simple and intuitive for easy operation.

After the system went live, it began collecting data from multiple channels. During the fall semester from September 2022 to January 2023, data from 300 students were collected, including learning behavior data (e.g., online study time, assignment submission records, classroom interaction logs) (Paraskevas, M., Tilleman, T., Eichen, Y. & Yellin, R. A., 2022), teaching resource utilization data (e.g., textbook and lecture slide views, video

watching duration), and teaching quality assessment data (e.g., exam scores, teacher evaluations). After data collection, the data preprocessing module cleaned and transformed the data, removing approximately 5% of invalid data to ensure data quality and usability.

To ensure effective use of the system by teachers and students, the university organized multiple training sessions. For teachers, the training covered system functionality, interpretation of analysis results, and how to adjust teaching strategies based on system recommendations. For students, the training focused on how to view personalized learning paths and resource recommendations. After the training, the system usage satisfaction rates for teachers and students reached 83% and 79%, respectively, indicating that the system's basic functions were recognized by users.

Table 2.

Project	**Content**
Data Collection Subjects	300 students
System Usage Satisfaction	Teachers: 83%; Students: 79%

5.3 System Application Effect Analysis

Through the system's data analysis module, teachers can clearly understand each student's learning progress and knowledge acquisition. For example, in the fall semester of 2022, in the course "Architectural Structure Design," the system analysis revealed that approximately 30% of students had poor learning outcomes in the chapter on "Concrete Structure Design." This was mainly reflected in low assignment completion rates (an average of only 56%) and unsatisfactory exam scores (average scores below 60). Based on the system's recommendations, the teacher adjusted the teaching strategy by increasing the class hours for this chapter and adding interactive sessions and case studies in the classroom. After the adjustment, the students' average scores in subsequent tests increased by 15 points, and the assignment completion rate rose to 82%. This demonstrates that the system's decision support function effectively helped teachers optimize their teaching strategies and improve teaching quality. (Paraskevas, M., Tilleman, T., Eichen, Y. & Yellin, R. A., 2022)

The system's personalized learning path and resource recommendation functions provided students with more precise learning support. For example, in the fall semester of 2022, in the course "Architectural Construction Technology," the system recommended personalized learning resources and paths for each student based on their learning behavior and score data. The results showed that students using personalized learning paths had an average score in the final exam 10 points higher than those who did not use them, and their learning satisfaction increased from 72% to 85%. Additionally, the system's learning behavior analysis function helped students better understand their learning habits, prompting them to adjust their learning strategies and improve learning efficiency.

During the system's usage, teachers and students provided several suggestions, including the addition of more interactive functions, optimization of the data visualization interface, and expansion to support more types of teaching resources. The development team iteratively optimized the system based on feedback to enhance its usability and scalability. For example, in the spring semester of 2023, the system added an online discussion area and real-time feedback functions to strengthen teacher-student interaction. It also expanded support for Virtual Reality (VR) teaching resources, providing students with a more immersive learning experience.

Table 3.

Project	**Content**
Proportion of Students with Poor Learning Outcomes	30%
Assignment Completion Rate (Before Adjustment)	56%
Exam Average Score (Before Adjustment)	Below 60
Exam Average Score Increase (After Adjustment)	15 points
Assignment Completion Rate Increase (After Adjustment)	82%
Final Exam Average Score Increase for Personalized Learning Path Students	10 points
Learning Satisfaction Increase	From 72% to 85%

5.4 Case Summary and Lessons Learned

Through the application practice at Huazhong University of Architecture and Science's Architectural Engineering Technology major, the big data-based decision support system for architectural education informatics achieved significant results. The system's scientific data analysis provided precise decision support for teachers, helping them optimize teaching strategies and significantly improve teaching quality. Meanwhile, the system's personalized learning path and resource recommendation functions significantly enhanced student learning outcomes and satisfaction, offering a more personalized and precise learning experience.

During the implementation process, several issues were encountered. For example, some data were missing and inaccurate during the initial data collection phase. By optimizing the data preprocessing module and adding data validation and cleaning mechanisms, this problem was effectively resolved. Some teachers and students had low acceptance of the new technology at the beginning of the system's use. Through multiple training sessions, detailed user manuals, and online help documents, the acceptance and usage satisfaction of users were gradually increased. As the data volume increased, the system experienced some delays in data processing and analysis. By optimizing algorithms and increasing server resources, the system's processing capabilities and response speed were improved.

These successful experiences and solutions to encountered problems provide valuable references for other architectural education institutions. Emphasizing data-driven teaching reform, focusing on personalized learning experiences, and continuously optimizing based on user feedback are key to enhancing the informatization level of architectural education. By introducing big data technology, architectural education institutions can better meet students' learning needs, optimize the use of teaching resources, improve teaching quality, and cultivate high-quality talents to meet the demands of the modern construction industry.

6. Conclusions and Future Work

6.1 Research Conclusions

This study focused on the big data-based decision support system for architectural education informatics. Through the application practice at Huazhong University of Architecture and Science's Architectural Engineering Technology major, the effectiveness of the system was verified. The research found that big data technology can significantly enhance the scientific and precise nature of teaching decision-making, optimize teaching strategies, and improve teaching quality. For example, in the course "Architectural Structure Design," the system helped teachers accurately identify students' learning difficulties. After adjusting the teaching strategies, the students' test average scores increased by 15 points, and the assignment completion rate rose from 60% to 85%. Meanwhile, the system's personalized learning path and resource recommendation functions effectively met students' individual needs, significantly improving learning outcomes and satisfaction. Additionally, the system's usability and scalability were verified in practical applications. Through continuous optimization, interactive functions were added, and support for more types of teaching resources was expanded, laying the foundation for the system's widespread application. Overall, the system provides strong support for the informatization of architectural education and has significant application value and potential for promotion.

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Investigating the Effects of Solar Radiation on Residential Architecture in Port Harcourt Metropolis

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Abstract

This study investigates the multifaceted effects of solar radiation on residential architecture within the Port Harcourt Metropolis, a region characterized by a tropical monsoon climate. The study aims to analyze the prevailing climatic conditions, assess the impact of solar radiation on indoor thermal comfort and energy consumption, evaluate current architectural design practices and material selections, and propose elective passive and active solar design strategies. Drawing upon a comprehensive literature review of scholarly articles, this research synthesizes existing knowledge on solar radiation characteristics, its implications for building performance, and climate-responsive design principles. Key findings indicate that high solar radiation in Port Harcourt significantly contributes to increased indoor temperatures, leading to discomfort and higher energy demands for cooling. Current architectural practices often fall short in adequately addressing these challenges, necessitating shift towards more sustainable and energy-efficient design approaches. The article proposes a range of strategies, including optimized building orientation, effective shading devices, enhanced natural ventilation techniques, and the judicious selection of building materials with favorable thermal properties. Furthermore, the integration of active solar systems, such as photovoltaic panels, is explored as a viable solution for reducing reliance on conventional energy sources. This study contributes to the academic discourse on climate-responsive architecture in tropical environments and offers practical recommendations for architects, urban planners, and homeowners in Port Harcourt, fostering the development of thermally comfortable, energy-efficient, and sustainable residential buildings. The insights gleaned from this research are crucial for mitigating the adverse effects of solar radiation, promoting environmental sustainability, and improving the quality of life for residents in the metropolis.

1. Introduction

1.1 Background of the Study

In an era defined by escalating environmental concerns and a burgeoning global population, the discourse surrounding sustainable development has gained unprecedented prominence. Central to this discourse is the imperative to re-evaluate human interactions with the built environment, particularly in the context of energy consumption and its concomitant ecological footprint. Buildings, in their design, construction, and operation, are significant contributors to global energy demand and greenhouse gas emissions. Estimates suggest that the building sector accounts for a substantial portion of worldwide energy consumption, ranging from 25% to 40% in developed nations, and is responsible for approximately 40% of global green house gas emissions (Enwin & Okorosa, 2020). This alarming reality underscores the urgent need for a paradigm shift in architectural practices, moving towards more energy-efficient and environmentally conscious approaches.

The concept of sustainable architecture emerges as a critical response to these challenges, advocating for design principles that minimize negative environmental impact, optimize resource efficiency, and enhance human well-being. A cornerstone of sustainable architecture is the judicious integration of natural climatic factors into building design, thereby reducing reliance on mechanical heating, ventilation, and air conditioning (HVAC) systems. Among these climatic factors, solar radiation stands out as a primary determinant of building performance, particularly in tropical and subtropical regions. Solar radiation, the radiant energy emitted by the sun, influences indoor thermal conditions, energy loads, and the overall comfort of building occupants. Its effects can be both beneficial, when harnessed for passive heating or daylighting, and detrimental, when leading to excessive heat gain and discomfort.

Tropical climates, characterized by high temperatures, humidity, and intense solar insulation throughout the year, present unique challenges and opportunities for architectural design. In such regions, managing solar heat gain becomes paramount to ensuring thermal comfort and minimizing cooling energy demands. Traditional architectural practices in many tropical areas have historically evolved to respond intuitively to these climatic realities, incorporating features such as large overhangs, natural ventilation strategies, and locally sourced materials with favorable thermal properties. However, rapid urbanization, globalization, and the adoption of Western architectural styles have often led to a disconnect from these time-tested, climate-responsive approaches, resulting in buildings that are ill-suited to their local environments and heavily reliant on energy-intensive mechanical cooling systems (Nwuche & Daminabo, 2022). This reliance not only exacerbates energy consumption and carbon emissions but also places a significant economic burden on building owners and occupants. Against this global backdrop, the Port Harcourt Metropolis in Nigeria serves as a compelling case study for investigating the intricate relationship between solar radiation and residential architecture. Situated within the Niger-Delta region, Port Harcourt experiences a tropical monsoon climate, characterized by abundant sunshine, high temperatures, and significant rainfall throughout much of the year (Nwuche & Daminabo, 2022; Enwin & Samuel, 2021). These climatic conditions, while offering potential for solar energy harvesting, also pose considerable challenges in terms of managing solar heat gain in buildings. The pervasive impact of solar radiation on the built environment in Port Harcourt necessitates a thorough examination of its effects on residential architecture, with a view to identifying and promoting design strategies that foster thermal comfort, enhance energy efficiency, and contribute to the broader goals of sustainable urban development. This study, therefore, seeks to delve into these critical aspects, providing insights that are not only academically significant but also practically relevant for shaping the future of residential construction in the metropolis.

1.2 Problem Statement

The Port Harcourt Metropolis, like many rapidly urbanizing cities in tropical regions, faces a critical challenge in balancing urban development with environmental sustainability. The prevailing architectural practices in the residential sector often overlook the profound influence of the local climate, particularly the intense solar radiation characteristic of the region. This oversight leads to a cascade of adverse effects on residential buildings and their occupants. Foremost among these is the significant increase in indoor temperatures, often exceeding comfortable levels, which directly compromises the thermal comfort of residents (Okoro & Ohochuku, 2024). The discomfort experienced within these thermally inefficient buildings compels occupants to rely heavily on mechanical cooling systems, such as air conditioners, to maintain habitable indoor environments. This reliance, in turn, translates into substantially higher energy consumption and inflated electricity bills, placing an undue economic burden on households and contributing to the overall energy crisis in Nigeria (Uchechukwu, 2022).

Beyond the immediate issues of thermal discomfort and increased energy costs, the relentless exposure to high solar radiation also impacts the long-term durability and structural integrity of residential buildings. Building materials, when subjected to continuous and intense solar exposure, can undergo accelerated degradation, leading to issues such as material fatigue, discoloration, and reduced lifespan (Nwuche & Daminabo, 2022). This necessitates more frequent maintenance and repair, further increasing the financial strain on home owners. Furthermore, the design choices that fail to account for solar radiation often result in suboptimal daylighting, leading to increased reliance on artificial lighting during daytime hours, thereby compounding the energy consumption problem.

The core of the problem lies in the apparent disconnects between traditional, climate-responsive architectural wisdom and contemporary building practices in Port Harcourt. While historical building forms in tropical climates inherently incorporated passive strategies to mitigate heat gain, modern construction often prioritizes aesthetics or cost-efficiency over climatic suitability. There is a discernible lack of widespread adoption and implementation of integrated design approaches that effectively harness the benefits of solar energy while simultaneously mitigating its detrimental effects. Existing research on the specific impacts of solar radiation on residential architecture in Port Harcourt, and the efficacy of various mitigation strategies within this unique climatic context, remains fragmented or insufficient to inform comprehensive policy and design guidelines. This

gap in knowledge and practice perpetuates the construction of thermally inefficient buildings, exacerbating energy poverty, environmental degradation, and compromising the quality of life for residents. Therefore, a thorough investigation into these issues is imperative to bridge this gap and pave the way for more sustainable and resilient residential architecture in the Port Harcourt Metropolis.

1.3 Research Questions

To address the identified problem and contribute to a more sustainable residential architectural landscape in Port Harcourt Metropolis, this study seeks to answer the following research questions:

1) How does solar radiation effects the thermal performance and energy consumption of residential buildings in Port Harcourt Metropolis?
2) What are the current design practices and material choices in Port Harcourt's residential architecture concerning the mitigation or utilization of solar radiation?
3) What passive and active solar design strategies can effectively mitigate the adverse effects of solar radiation and enhance thermal comfort and energy efficiency in residential buildings within Port Harcourt Metropolis?

1.4 Objectives of the Study

Stemming from the afore mentioned research questions, the primary objectives of this study are:

1) To analyze the climatic characteristics of Port Harcourt Metropolis, with a specific focus on solar radiation patterns and their seasonal variations.
2) To assess the impact of solar radiation on the indoor thermal comfort and energy consumption of typical residential buildings in Port Harcourt.
3) To evaluate current architectural design practices and materials elections employed in residential construction within Port Harcourt in relation to solar heat gain and loss.
4) To propose and critically examine effective passive and active solar design strategies tailored for residential architecture in Port Harcourt Metropolis, aimed at improving thermal performance and energy efficiency.

1.5 Significance of the Study

This study holds significant implications for various stakeholders, contributing to both academic knowledge and practical applications within the built environment of Port Harcourt Metropolis and other similar tropical regions. Academically, this research will enrich the existing body of literature on climate-responsive architecture, particularly in the context of rapidly developing urban centers in West Africa. By providing a comprehensive analysis of the effects of solar radiation on residential buildings in Port Harcourt, it will serve as a valuable reference for future studies, fostering a deeper understanding of the complexities involved in designing sustainable buildings in tropical climates. The detailed examination of climatic data, current practices, and proposed strategies will offer a nuanced perspective that can inform theoretical frameworks and research methodologies in architectural science.

From a practical standpoint, the findings and recommendations of this study are poised to benefit a wide array of professionals and the general populace. For architects and urban planners operating in Port Harcourt, this research will provide evidence-based guidelines for designing residential buildings that are inherently more energy-efficient and thermally comfortable. It will highlight critical design considerations, material selections, and construction techniques that can mitigate the adverse effects of solar radiation, thereby reducing the reliance on energy-intensive mechanical cooling systems. This, in turn, can lead to substantial reductions in energy consumption and associated costs for homeowners, addressing a pressing economic concern in the region. Furthermore, the study's emphasis on sustainable practices aligns with global efforts to combat climate change, offering a localized approach to reducing carbon emissions from the building sector.

For policymakers and regulatory bodies, this research will serve as a crucial resource for developing and implementing building codes and urban planning policies that promote climate-responsive design. The insights gained can inform incentives for green building practices, regulations on building orientation and shading, and standards for material performance, ultimately shaping a more sustainable and resilient urban fabric. Moreover, homeowners and prospective home builders in Port Harcourt will gain a clearer understanding of how design choices can directly impact their living comfort and operational costs. By providing practical recommendations, the study empowers individuals to make informed decisions that contribute to their well-being and environmental stewardship. Ultimately, this research aims to foster a built environment in Port Harcourt that is not only aesthetically pleasing but also functionally superior, economically viable, and environmentally responsible, thereby improving the overall quality of life for its residents.

2. Literature Review

2.1 Solar Radiation and Its Characteristics

Solar radiation, the electromagnetic radiation emitted by the sun, is the primary energy source driving Earth's climate system and profoundly influencing the built environment. Understanding its characteristics is fundamental to designing energy-efficient and thermally comfortable buildings, particularly in regions with high solar insolation like Port Harcourt. Solar radiation reaching the Earth's surface can be broadly categorized into three components: direct, diffuse, and reflected radiation.

Direct Radiation: Also known as beam radiation, this component travels in a straight line from the sun to the Earth's surface without being scattered or absorbed by the atmosphere. It casts sharp shadows and is the most intense form of solar radiation. The intensity of direct radiation is influenced by the sun's altitude (angle above the horizon), which varies with time of day, season, and geographical latitude. In tropical regions, the sun's path is often high in the sky, leading to intense direct radiation, especially around solar noon.

Diffuse Radiation: This component results from the scattering of direct solar radiation by atmospheric constituents such as clouds, aerosols, and dust particles. Diffuse radiation comes from all directions of the sky, and its intensity is higher on cloudy days when direct radiation is significantly attenuated. Even on clear days, a substantial portion of solar radiation reaching the Earth's surface is diffuse, contributing to ambient light and heat gain from all exposed surfaces of a building. The presence of significant cloud cover, as often experienced in Port Harcourt during its rainy season, means that diffuse radiation plays a crucial role in the overall solar heat gain of buildings (Okoro & Ohochuku, 2024).

Reflected Radiation: This is the solar radiation that has been reflected from surrounding surfaces, such as the ground, adjacent buildings, or water bodies. The amount of reflected radiation depends on the albedo (reflectivity) of these surfaces. Light-colored surfaces, for instance, have a higher albedo and reflect more solar radiation, which can contribute to heat gain through building facades and windows. Conversely, dark surfaces absorb more radiation, leading to higher surface temperatures and re-radiation of heat.

Measurement and Data Analysis of Solar Radiation: The quantification of solar radiation is crucial for informed architectural design. Solar radiation is typically measured in watts per square meter (W/m^2) or kilowatt-hours per square meter per day($kWh/m^2/day$). Instruments such as pyranometers measure global horizontal irradiance (GHI), which is the total solar radiation incident on a horizontal surface (sum of direct and diffuse). Pyrheliometers measure direct normal irradiance (DNI), and shaded pyranometers measure diffuse horizontal irradiance (DHI). Long-term meteorological data, often collected by weather stations and organizations like the World Meteorological Organization (WMO), provide valuable insights into regional solar radiation patterns (Nwuche & Daminabo, 2022).

For Port Harcourt, studies indicate a significant solar energy resource. The annual average daily solar radiation in the Niger-Delta region, where Port Harcourt is located, is approximately 5.25 $kWh/m^2/day$, with variations ranging from 3.5 $kWh/m^2/day$ (Uchechukwu, 2022). The monthly average daily solar radiation in Port Harcourt is reported to be between 4000 and 5000 Whr/m^2(4-5 $kWh/m^2/day$), with daily sunshine durations ranging from 4 to 8 hours (Enwin & Samuel, 2021). This high level of solar insulation underscores the importance of understanding its characteristics and implications for building design in the metropolis. The consistent presence of high solar radiation throughout the year, even with seasonal variations in cloud cover, means that buildings are continuously exposed to significant solar heat gain, necessitating effective mitigation strategies.

2.2 Effects of Solar Radiation on Buildings

Solar radiation, while a vital source of light and energy, can have profound and often detrimental effects on buildings, particularly in hot and humid climates like that of Port Harcourt. These effects primarily manifest as unwanted heat gain, leading to a cascade of consequences for indoor thermal comfort, energy consumption, and the long-term integrity of building materials.

Heat Gain Mechanisms: Solar radiation penetrates the building envelope through various mechanisms, contributing to internal heat gain. The primary mechanisms include:

- **Conduction:** Heat transfer through opaque building elements such as walls and roofs. When solar radiation strikes the exterior surface of a wall or roof, it heats up the material. This heat then conducts through the material to the cooler interior surface. The rate of heat conduction depends on the material's thermal conductivity, thickness, and the temperature difference across it. Materials with high thermal mass can absorb and store a significant amount of heat, which can then be released into the interior space later, often at night (Nwuche & Daminabo, 2022).
- **Convection:** Heat transfer through the movement of fluids (air or water). Solar radiation can heat the air adjacent to exterior surfaces, causing it to rise and be replaced by cooler air, creating convective currents.

Within a building, warm air can also move from hotter to cooler spaces through natural convection, contributing to heat distribution.

- **Radiation:** Direct transfer of heat from a warmer surface to a cooler surface through electromagnetic waves. This is the most direct way solar radiation contributes to heat gain. Sunlight passing through windows directly heats interior surfaces and occupants. Even opaque surfaces, once heated by solar radiation, re-radiate that heat into the interior space.

Impact on Indoor Thermal Comfort: The most immediate and noticeable effects of excessive solar radiation on residential buildings in Port Harcourt is the compromise of indoor thermal comfort. High solar heat gain leads to elevated indoor air temperatures, often exceeding the comfortable range for occupants (Okoro & Ohochuku, 2024). This creates an uncomfortable living environment, characterized by sensations of stuffiness, humidity, and overall thermal dissatisfaction. In a tropical climate where cooling is required almost year-round, this issue is particularly acute (Nwuche & Daminabo, 2022). The human body responds to these elevated temperatures by sweating, which can lead to dehydration and heat stress if prolonged. The inability to achieve thermal balance naturally within the building forces occupants to seek artificial means of cooling, thereby initiating a cycle of increased energy consumption.

Increased Energy Consumption for Cooling: The direct consequence of compromised thermal comfort due to solar heat gain is a significant increase in the energy demand for mechanical cooling. Air conditioning units, fans, and other cooling appliances are extensively used to bring down indoor temperatures to acceptable levels. This reliance on active cooling systems translates directly into higher electricity consumption and, consequently, higher utility bills for households (Enwin & Okorosa, 2020; Uchechukwu, 2022). In a region like Port Harcourt, where electricity supply can be inconsistent and expensive, this added energy burden exacerbates energy poverty and places a considerable economic strain on residents. Moreover, the increased energy consumption contributes to a larger carbon footprint for the building sector, counteracting efforts towards environmental sustainability.

Degradation of Building Materials: Beyond thermal discomfort and energy costs, prolonged exposure to intense solar radiation can accelerate the degradation of building materials. Ultraviolet (UV) radiation, a component of solar radiation, can cause chemical break down of materials, leading to fading, cracking, warping, and embrittlement. Paints can peel, wooden elements can rot, and plastic components can become brittle and discolored (Nwuche & Daminabo, 2022; Okoro & Ohochuku, 2024). The high temperatures induced by solar absorption can also cause thermal expansion and contraction, leading to stress on building components and potentially structural damage over time. This material degradation not only compromises the aesthetic appeal of buildings but also reduces their lifespan, necessitating more frequent maintenance, repairs, and premature replacement of components, thereby increasing the overall lifecycle costs of the building.

2.3 Climate of Port Harcourt Metropolis

Understanding the specific climatic conditions of Port Harcourt Metropolis is paramount for developing effective climate-responsive architectural solutions. Located in the Niger-Delta region of southern Nigeria, Port Harcourt experiences a tropical monsoon climate (Köppen climate classification: Am), characterized by distinct wet and dry seasons, consistently high temperatures, and significant humidity throughout the year (Nwuche & Daminabo, 2022). This climatic profile presents both opportunities for harnessing natural energy and challenges for maintaining indoor thermal comfort.

Temperature: The temperature in Port Harcourt remains relatively high and consistent throughout the year, with minimal diurnal and annual variations. Average annual temperatures typically range between 21°C and 34°C (Okoro & Ohochuku, 2024). The monthly average maximum temperatures hover around 30-33°C, while minimum temperatures range from 21-23°C (Nwuche & Daminabo, 2022). The warmest period is generally from February to May, coinciding with the dry season, while the wet season months of July and August record slightly lower temperatures, ranging from approximately 16°C to 24°C (Okoro & Ohochuku, 2024). This consistently warm environment means that cooling is a year-round requirement for comfortable indoor spaces.

Humidity: Relative humidity levels in Port Harcourt are consistently high, typically ranging from 70% to 90%, and rarely falling below 60% (Enwin & Samuel, 2021; Okoro & Ohochuku, 2024). This high humidity contributes significantly to thermal discomfort, as it inhibits the body's natural cooling mechanism through evaporative sweating. Furthermore, persistent high humidity can lead to issues such as mold growth, material degradation (e.g., water seepage, rusting of iron, rotting of timber), and a general feeling of stuffiness within buildings (Nwuche & Daminabo, 2022).

Rainfall: Port Harcourt receives a substantial amount of rainfall annually, averaging between 2500mm and 3000mm, with significant monthly variations (Enwin & Samuel, 2021; Okoro & Ohochuku, 2024). The rainy season typically extends from April to October, with peak rainfall occurring in July and September. Even during the short dry spell, rainfall can occur. This high precipitation necessitates robust water proofing and drainage

strategies in building design to prevent water ingress and associated damage.

Wind: The predominant wind direction in Port Harcourt varies seasonally. During the rainy season, the south-west wind is dominant, while the north-west wind prevails during the dry season (Okoro & Ohochuku, 2024). Ideal wind speeds for indoor thermal comfort are generally considered to be between 0.1 and 5.0m/s. Harnessing these prevailing winds for natural ventilation is a key strategy for passive cooling, but careful consideration of wind direction and speed is required to optimize air flow and avoid discomfort from strong gusts.

Sunshine Hours and Solar Radiation: As previously discussed, Port Harcourt experiences significant solar radiation. The monthly average daily solar radiation is estimated between 4000 and 5000 W hr/m² (4-5 kWh/m²/day), with daily sunshine durations ranging from 4 to 8 hours (Enwin & Samuel, 2021). While there is substantial sunshine during the dry season, the rainy season sees limited sunshine due to prevalent cloud cover, with average sunshine duration in August and April being as low as 1.7 hours (Okoro & Ohochuku, 2024). Despite the cloud cover, the overall solar heat gain remains a critical factor due to the high diffuse radiation component. The intensity of solar radiation, coupled with high temperatures and humidity, makes solar heat gain mitigation a primary design challenge.

In summary, the climate of Port Harcourt is characterized by a consistently hot and humid environment with abundant solar radiation and high rainfall. These conditions collectively pose significant challenges for residential architecture, primarily in terms of managing solar heat gain, ensuring adequate natural ventilation, and preventing moisture-related issues. Effective architectural design in this metropolis must therefore be inherently climate-responsive, aiming to minimize heat ingress, maximize natural cooling, and ensure building durability in the face of persistent humidity and rainfall.

2.4 Passive Solar Design Strategies

Passive solar design harnesses solar energy without the use of mechanical systems, relying instead on architectural elements and material properties to manage heat gain and loss. In a hot and humid climate like Port Harcourt, the primary objective of passive solar design is to minimize unwanted solar heat gain and promote natural cooling to enhance thermal comfort and reduce energy consumption. Several key strategies are employed in this regard:

Building Orientation and Form: The orientation of a building relative to the sun's path is one of the most fundamental passive solar design considerations. In tropical climates, where the sun is often high in the sky, optimizing orientation is crucial to minimize direct solar exposure on large surfaces. Studies recommend orienting the longest axis of a building along the east-west direction to reduce solar heat gain, as the east and west facades receive intense low-angle sun in the mornings and afternoons, respectively (Enwin & Okorosa, 2020; Okoro & Ohochuku, 2024). Conversely, the north and south facades, which receive less direct solar radiation, should have fewer openings. Building form also plays a role; compact forms with smaller surface area-to-volume ratios can reduce heat gain, while elongated forms along the east-west axis can maximize exposure to prevailing winds for natural ventilation.

Shading Devices: Effective shading is paramount in mitigating solar heat gain, especially in regions with high solar intensity. Shading devices intercept direct solar radiation before it reaches the building envelope, preventing heat from entering the interior. Various types of shading devices can be employed:

- **Overhangs:** Horizontal projections above windows and walls are effective in shading south-facing facades from high-angle sun. In Port Harcourt, where the sun's path is often near vertical, appropriately sized overhangs are essential (Okoro & Ohochuku, 2024).
- **Vertical Fins/Louvers:** These are vertical projections on either side of windows, effective in shading east and west-facing facades from low-angle sun. Adjustable louvers can provide dynamic shading throughout the day.
- **Egg-crate Louvers:** A combination of horizontal and vertical elements, offering comprehensive shading from various sun angles.
- **Vegetation:** Deciduous trees and strategically planted shrubs can provide effective seasonal shading, blocking intense summer sun while allowing some solar penetration in cooler periods. Plantations can also shade specific facades, such as the north facade in Port Harcourt, which is exposed to the North-East Trade wind during the dry season (Nwuche & Daminabo, 2022).
- **Balconies and Recessed Openings:** These architectural features inherently provide self-shading to windows and walls.

Natural Ventilation: Maximizing natural air flow through a building is a highly effective passive cooling strategy in hot and humid climates. Natural ventilation relies on pressure differences created by wind or

temperature differentials to draw cooler outdoor air into the building and expel warmer indoor air. Key techniques include:

- **Cross-Ventilation:** Achieved by placing openings (windows, doors) on opposite sides of a room or building to allow air to flow directly through. For optimal cross-ventilation, windows should ideally be diagonally opposite each other (Enwin & Okorosa, 2020).
- **Stack Effect (Buoyancy-Driven Ventilation):** This phenomenon utilizes the principle that warm air rises. By incorporating high-level openings (e.g., roof vents, clerestory windows) and low-level openings, warmer air escapes through the top, creating a negative pressure that draws cooler air in from below (Enwin & Samuel, 2021). The effectiveness of the stack effect is directly proportional to the temperature difference between indoor and outdoor environments.

Wind Catchers /Towers: Traditional architectural elements designed to capture prevailing winds and direct them in to the building, often incorporating evaporative cooling mechanisms.

Permeable Building Layouts: Designing buildings with courtyards or open plans can facilitate air flow and improve interior illumination (Okoro & Ohochuku, 2024).

Thermal Mass and Insulation: The strategic use of thermal mass and insulation is critical for moderating indoor temperatures. Thermal mass refers to the ability of a material to absorb, store, and release heat. In hot climates, materials with high thermal mass (e.g., concrete, brick) can absorb daytime heat and release it slowly during cooler nights, thereby dampening indoor temperature fluctuations (Nwuche & Daminabo, 2022). However, proper ventilation is necessary to purge the stored heat at night. Insulation, on the other hand, resists heat flow. While often associated with cold climates, insulation is equally important in hot climates to prevent heat gain from the exterior. For roofs, a double roof with a lightweight, highly reflective outer layer and insulation between layers can significantly reduce heat transfer (Nwuche & Daminabo, 2022). Doubling the thickness of external walls can also reduce cooling loads (Enwin & Okorosa, 2020).

Material Selection (Color, U-value, SHGC): The choice of building materials significantly impacts a building's thermal performance. Materials should be selected based on their thermal properties, including:

- **Color:** Light-colored exterior surfaces, particularly roofs and walls, reflect a greater portion of solar radiation, thereby reducing heat absorption. Using white or light-colored external wall finishes can lead to substantial energy savings (Enwin & Okorosa, 2020; Okoro & Ohochuku, 2024). Dark colors, conversely, absorb more heat.
- **U-value (Thermal Transmittance):** This measures the rate of heat transfer through a material or assembly. Lower U-values indicate better insulating properties. Materials with low U-values are desirable to minimize heat gain through the building envelope.
- **SHGC (Solar Heat Gain Coefficient):** For windows, SHGC represents the fraction of incident solar radiation that enters a building as heat. Lower SHGC values are preferred in hot climates to reduce solar heat gain through glazing.

  Specific Materials: Perlite plaster, for instance, has been shown to have a lower thermal transmittance value compared to cement screed, making it a more energy-efficient option for walls (Enwin & Okorosa, 2020). Materials that repel heat and remain cool, while also being able to withstand high rainfall, are ideal for Port Harcourt's climate (Nwuche & Daminabo, 2022).

Daylighting Strategies: While primarily focused on reducing artificial lighting, effective daylighting also contributes to passive solar design by minimizing heat generated by artificial lights. Strategies include optimizing window placement, size, and orientation, and using light shelves or courtyards to distribute natural light deeper into the building (Okoro & Ohochuku, 2024). However, care must be taken to control glare and prevent excessive solar heat gain through large glazed areas.

2.5 Active Solar Design Strategies

Active solar design involves the use of mechanical or electrical equipment to collect, store, and distribute solar energy. Unlike passive systems that rely on natural processes, active systems require external energy input for their operation. In the context of residential architecture, active solar technologies primarily focus on electricity generation and water heating, offering significant potential for reducing reliance on conventional energy sources and mitigating the environmental impact of buildings.

Photovoltaic (PV) Systems for Electricity Generation: Photovoltaic (PV) systems convert sunlight directly into electricity using semiconductor materials. This technology has seen rapid advancements in efficiency and cost reduction, making it an increasingly viable option for residential applications, even in regions with inconsistent grid supply. In Port Harcourt, where electricity supply can be unreliable and expensive, PV systems

offer a compelling alternative for power generation (Uchechukwu, 2022). The high solar radiation in the region, with an annual average daily solar radiation of approximately 5.25kWh/m²/day in the Niger-Delta, presents an excellent resource for PV deployment (Uchechukwu, 2022).

Residential PV systems typically consist of solar panels (modules) installed on rooftops or facades, an inverter to convert direct current (DC) electricity from the panels into alternating current (AC) for household use, and often a battery bank for energy storage to ensure power availability during periods of low sunlight or grid outages. The integration of PV panels into building design can take various forms, including:

- **Roof top Installations:** The most common application, where panels are mounted on the roof, optimizing for solar exposure. Proper installation and orientation are crucial for maximizing power collection (Wariboko, 2019).
- **Building-Integrated Photovoltaics (BIPV):** PV materials are integrated directly into the building envelope, serving as architectural elements such as facades, windows (transparent solar energy windows), or roofing materials. BIPV offers aesthetic advantages and can reduce overall building material costs, while simultaneously generating electricity (Uchechukwu, 2022).

While the initial capital investment for PV systems can be substantial, the long-term benefits include significant reductions in electricity bills, quiet operation, and environmental friendliness (Wariboko, 2019). The economic viability of PV systems in Port Harcourt is further enhanced by the high cost and unreliability of grid electricity, making the payback period potentially shorter compared to regions with stable and cheaper power. However, challenges such as the quality of components, lack of structured maintenance programs, and the need for proper installation techniques need to be addressed for widespread adoption (Wariboko, 2019).

Solar Water Heating Systems: Solar water heating (SWH) systems utilize solar energy to heat water for domestic use, significantly reducing the energy required for conventional water heaters. These systems typically consist of solar collectors (flat-plate or evacuated tube collectors) that absorb solar radiation and transfer the heat to water, and an insulated storage tank. SWH systems operate on the principle of thermosiphon, where heated water rises to the storage tank, and cooler water flows down to the collector, creating a continuous circulation (Wariboko, 2019).

In Port Harcourt, the abundant sunshine makes SWH systems a highly efficient and cost-effective solution for hot water demand. By pre-heating water using solar energy, households can substantially lower their electricity or gas consumption for water heating, contributing to overall energy efficiency and reduced utility costs. The integration of SWH systems into residential architecture can be seamless, with collectors often installed on rooftops or integrated into the building facade.

Integration of Active Systems into Building Design: The successful implementation of active solar technologies in residential architecture requires careful consideration during the design phase. This includes optimizing the orientation and tilt of solar collectors for maximum solar exposure, ensuring adequate structural support for roof top installations, and integrating wiring and plumbing seamlessly into the building fabric. Early consideration of active solar systems in the design process can lead to more aesthetically pleasing and functionally efficient installations, maximizing their energy-saving potential and contributing to the overall sustainability of the building. Furthermore, combining active solar systems with passive design strategies can create a holistic approach to energy management, where passive measures reduce the overall energy demand, and active systems meet the remaining energy needs efficiently (Wariboko, 2019).

2.6 Energy Efficiency in Residential Architecture

Energy efficiency in residential architecture is a critical component of sustainable development, aiming to minimize the energy consumption of buildings while maintaining or enhancing indoor comfort and functionality. This involves a holistic approach that considers the building as an integrated system, where various elements interact to influence overall energy performance. In the context of Port Harcourt Metropolis, achieving energy efficiency is crucial for mitigating the adverse effects of solar radiation, reducing operational costs, and contributing to environmental sustainability.

Concepts of Energy-Efficient Buildings: An energy-efficient building is designed to use less energy for heating, cooling, lighting, and other operations compared to conventional buildings, without compromising the comfort or health of its occupants. This is achieved through a combination of passive design strategies, optimized building envelope performance, efficient mechanical systems, and the integration of renewable energy sources. The core principle is to reduce energy demand first through intelligent design, and then to meet the remaining demand efficiently and sustainably (Enwin & Okorosa, 2020).

Building Envelope Performance (ETTV): The building envelope — comprising the roof, walls, windows, and floor — acts as the primary barrier between the indoor and outdoor environments. Its performance is critical in

determining the energy consumption of a building, particularly in managing heat transfer. In hot climates, minimizing heat gain through the envelope is paramount. A key metric used to assess the thermal performance of the building envelope is the **Envelope Thermal Transfer Value (ETTV)**. The ETTV quantifies the total heat gain through the external walls and windows of a building, taking into account three main components (Enwin & Okorosa, 2020):

1) **Heat conduction through opaque walls:** Heat transfer through solid wall sections.
2) **Heat conduction through glass windows:** Heat transfer through glazing.
3) **Solar radiation through glass windows:** Direct solar heat gain through transparent surfaces.

The ETTV formula is typically expressed as:

Where:*ETTV: Envelope Thermal Transfer Value (W/m²) *WWR: Window-to-wall ratio (fenestration area / gross area of exterior wall) *Uw: Thermal transmittance of opaque wall(W/m² K) *Uf: Thermal transmittance of fenestration (W/m² K) *CF: Correction factor for solar heat gain through fenestration *SC: Shading Coefficient of fenestration A lower ETTV indicates a more energy-efficient building envelope, signifying reduced heat gain and, consequently, lower cooling loads. Optimizing each component of the ETTV through careful design and material selection is crucial for achieving energy efficiency in tropical residential buildings.

2.7 Sustainable Building Materials and Construction Methods

The selection of building materials plays a pivotal role in the energy performance and environmental impact of residential architecture. Sustainable building materials are those that have a low environmental impact throughout their lifecycle, from extraction and manufacturing to transportation, use, and disposal. In the context of solar radiation, materials that possess favorable thermal properties are essential. For instance, materials with high reflectivity and low thermal conductivity can significantly reduce heat absorption and transfer into the building interior. The use of light-colored exterior finishes, particularly for roofs and walls, has been shown to reduce cooling energy consumption by reflecting a greater portion of solar radiation (Enwin & Okorosa, 2020; Okoro & Ohochuku, 2024). Furthermore, materials with good thermal mass can help in moderating indoor temperature swings. The choice of materials should also consider their durability and resistance to degradation under the specific climatic conditions of Port Harcourt, including high humidity and intense solar exposure (Nwuche & Daminabo, 2022).

Construction methods also contribute to energy efficiency. Proper insulation installation, sealing of air leaks, and attention to detail in construction can prevent unwanted heat gain and ensure the effectiveness of passive design strategies. The integration of traditional building techniques that have evolved to suit local climates, combined with modern sustainable practices, can lead to highly energy-efficient and culturally appropriate residential architecture.

Case Studies or Examples: While specific detailed case studies of energy-efficient residential buildings in Port Harcourt are limited in the reviewed literature, the principles discussed are widely applicable. Examples from similar hot and humid climates globally demonstrate the effectiveness of integrated design approaches. These often feature optimized orientation, extensive shading, natural ventilation systems (e.g., courtyards, wind towers), high-performance glazing, and the use of local, sustainable materials. The success of such projects underscores the potential for significant energy savings and enhanced thermal comfort when climate-responsive design is prioritized from the outset. The challenge for Port Harcourt lies in adapting these principles to the local context, considering socio-economic factors, and promoting their widespread adoption through education, policy, and practical demonstration.

3. Methodology

3.1 Research Design

This study employs a descriptive and analytical research design to investigate the effects of solar radiation on residential architecture in Port Harcourt Metropolis and to propose effective mitigation strategies. The descriptive component involves a detailed characterization of the climatic conditions of Port Harcourt, with a particular emphasis on solar radiation patterns, and an assessment of the current state of residential architectural practices in the region. This includes identifying prevalent building typologies, material choices, and design approaches. The analytical component focuses on examining the relationships between solar radiation, building design parameters, and their impact on indoor thermal comfort and energy consumption. This involves synthesizing information from existing scholarly literature and, where applicable, drawing insights from relevant case studies or theoretical models.

The research design is primarily qualitative in its approach to understanding architectural practices and their implications, complemented by quantitative data analysis for climatic parameters. It does not involve primary data collection through surveys or direct measurements of buildings, but rather relies on a comprehensive review

and synthesis of published academic works, meteorological data, and established architectural principles. This approach allows for a broad yet in-depth exploration of the topic, leveraging existing knowledge to build a robust argument and propose informed recommendations. The iterative process of literature review, data synthesis, and conceptual analysis forms the core of this research, ensuring a holistic understanding of the complex interplay between climate, architecture, and human comfort in the study area.

3.2 Study Area

The study focuses on the Port Harcourt Metropolis, the capital and largest city of Rivers State, Nigeria. Geographically, Port Harcourt is situated in the Niger-Delta region, a coastal area characterized by a low-lying topography, numerous rivers, and a tropical monsoon climate. The city is a major economic hub, particularly for the oil and gas industry, which has driven significant urban expansion and population growth over the past few decades. This rapid urbanization has led to a diverse architectural landscape, ranging from traditional residential structures to modern, often imported, building typologies.

Residential architecture in Port Harcourt typically comprises a mix of detached houses, semi-detached houses, and multi-family apartment buildings. The construction materials commonly employed include concrete blocks, cement screed, and corrugated iron or concrete roofs. While some newer developments may incorporate contemporary designs, many residential buildings in the metropolis reflect a blend of local adaptations and influences from global architectural trends. The high population density in certain areas, coupled with the prevailing climatic conditions, makes Port Harcourt an ideal and critical location for investigating the effects of solar radiation on residential buildings. The findings from this study, while specific to Port Harcourt, are expected to have broader applicability to other urban centers in similar tropical humid climates across West Africa.

3.3 Data Collection

Given the nature of this study as a comprehensive literature review and analytical synthesis, data collection primarily involved the systematic retrieval and examination of existing scholarly publications and publicly available meteorological data. The sources of information included:

- **Scholarly Articles and Journals:** Academic data bases (e.g., Science Direct, Research Gate, Google Scholar, academic journal websites) were extensively searched using keywords such as “solar radiation Port Harcourt,” “residential architecture Nigeria,” “thermal comfort tropical climate,” “passive solar design,” “energy efficiency buildings,” and “building materials heat gain.” Emphasis was placed on recent publications to ensure the relevance and currency of the information. Articles focusing on Port Harcourt Metropolis or other regions with similar climatic conditions were prioritized.
- **Conference Proceedings and Theses:** Relevant papers presented at academic conferences and post graduate theses were also consulted to gather specialized insights and localized studies.
- **Meteorological Data:** Climatic data for Port Harcourt, including temperature, relative humidity, rainfall, wind speed and direction, sun shine hours, and solar radiation intensity, were sourced from reputable meteorological organizations and academic studies that have analyzed such data for the region. Organizations like the World Meteorological Organization (WMO) and national meteorological agencies provide foundational data for climatic analysis.

The collected data encompassed both qualitative information (e.g., descriptions of design strategies, material properties, and their implications) and quantitative data (e.g., average temperatures, solar radiation values, rainfall amounts). The process involved critically evaluating the credibility and relevance of each source to ensure the robustness of the findings and conclusions drawn in this study.

3.4 Data Analysis

The data analysis forth is study was primarily based on a qualitative synthesis of information derived from the extensive literature review, complemented by a quantitative interpretation of climatic data. The analytical approach involved several steps:

- **Thematic Analysis of Literature:** Scholarly articles, reports, and other relevant documents were subjected to thematic analysis. This involved identifying recurring themes, key concepts, and significant findings related to solar radiation, its effects on buildings, and climate- responsive design strategies. Information was categorized into areas such as climatic characteristics, heat gain mechanisms, thermal comfort issues, material performance, and passive/active design interventions. Conflicting findings or research gaps were also noted to inform the discussion and recommendations.
- **Interpretation of Climatic Data:** Quantitative climatic data (e.g., average temperatures, solar radiation values, humidity levels, wind patterns) for Port Harcourt were interpreted to establish the specific environmental context. This involved understanding the seasonal variations and peak periods of solar

exposure, which are critical for assessing their impact on building performance. While direct statistical analysis of raw meteorological data was beyond the scope of this literature-based study, the findings from existing analyses by other researchers were critically reviewed and integrated.

- **Evaluation of Design Practices:** Current architectural design practices and material choices in Port Harcourt were evaluated against established principles of climate-responsive design and energy efficiency. This involved assessing how well existing buildings and common construction methods address the challenges posed by solar radiation, drawing insights from the reviewed literature that discussed local building typologies and their performance.
- **Comparative Analysis of Strategies:** Various passive and active solar design strategies were comparatively analyzed based on their theoretical effectiveness and documented performance in similar climatic contexts. This involved assessing their potential for mitigating solar heat gain, enhancing thermal comfort, and reducing energy consumption in residential buildings in Port Harcourt. The feasibility and applicability of these strategies within the local socio-economic and construction landscape were also considered.

The synthesis of these analytical processes allowed for the development of a comprehensive understanding of the problem, the identification of effective solutions, and the formulation of practical recommendations for sustainable residential architecture in the Port Harcourt Metropolis.

4. Results and Discussion

4.1 Climatic Profile of Port Harcourt and Solar Radiation Patterns

The analysis of existing meteorological data and scholarly studies reveals a distinct climatic profile for the Port Harcourt Metropolis, characterized by conditions that significantly influence building performance, particularly concerning solar radiation. As a city situated within the tropical monsoon climate zone (Am), Port Harcourt experiences consistently high temperatures, elevated humidity, and substantial rainfall throughout the year, with solar radiation being a pervasive and influential climatic factor.

Temperature and Humidity: Average annual temperatures in Port Harcourt consistently range between 21°C and 34°C, with minimal seasonal fluctuations (Okoro & Ohochuku, 2024). This narrow temperature range, coupled with average maximum temperatures often exceeding 30°C, indicates a continuous need for cooling to maintain indoor thermal comfort. The high relative humidity, typically between 70% and 90%, exacerbates the sensation of heat and limits the effectiveness of evaporative cooling, making the humid heat particularly oppressive (Enwin & Samuel, 2021; Okoro & Ohochuku, 2024; Budnukaeku & Weli, 2022, Alexander & Weli, 2023). This combination of high temperature and humidity means that even moderate solar heat gain can quickly push indoor conditions beyond comfortable limits.

Rainfall and Wind Patterns: Port Harcourt receives abundant rainfall, averaging 2500mm to 3000mm annually, primarily concentrated during the wet season from April to October (Enwin & Samuel, 2021; Okoro & Ohochuku, 2024). While rainfall itself does not directly contribute to solar heat gain, the associated cloud cover during the wet season can reduce direct solar radiation. However, the high humidity and latent heat associated with rainfall still contribute to the overall thermal load. Wind patterns, predominantly south-westerly during the rainy season and north-westerly during the dry season, offer potential for natural ventilation, but their effectiveness in dense urban areas can be limited (Okoro & Ohochuku, 2024).

Solar Radiation Intensity and Duration: The most critical climatic factor for this study is solar radiation. Despite seasonal variations in cloud cover, Port Harcourt experiences high levels of solar insolation throughout the year. Studies indicate an annual average daily solar radiation of approximately 5.25kWh/m²/day in the Niger-Delta region, with monthly averages in Port Harcourt ranging from 4000 to 5000 Whr/m² (4-5 kWh/m²/day) (Uchechukwu, 2022; Enwin & Samuel, 2021). The daily sunshine duration typically ranges from 4 to 8 hours. While the dry season (February to May) sees substantial direct sunshine, the rainy season experiences limited direct sun due to cloud cover, with average sunshine duration in August and April being as low as 1.7 hours (Okoro & Ohochuku, 2024). However, even on cloudy days, diffuse radiation remains significant, contributing to overall heat gain.

Peak Solar Exposure Periods: Given the sun's path in tropical regions, facades facing east and west receive intense low-angle solar radiation during morning and afternoon hours, respectively. The roof and south-facing facades (in the Northern Hemisphere) receive significant high-angle solar radiation around solar noon. In Port Harcourt, the pervasive nature of solar radiation, whether direct or diffuse, means that all exposed surfaces of a building are subjected to considerable solar heat gain for much of the day. This constant exposure necessitates comprehensive design strategies to mitigate heat ingress and maintain comfortable indoor environments.

In summary, the climatic profile of Port Harcourt presents a challenging environment for residential architecture.

The combination of high temperatures, oppressive humidity, and intense solar radiation (both direct and diffuse) creates a continuous demand for cooling. Effective architectural responses must therefore prioritize strategies that minimize solar heat gain and promote natural cooling, acknowledging the year-round nature of these climatic stressors. The following table summarizes the key climatic characteristics of Port Harcourt relevant to building design:

Table 1. Summary of Key Climatic Characteristics in Port Harcourt Metropolis

Climatic Element	Characteristics in Port Harcourt Metropolis
Temperature	Consistently high (21-34°Cannually), minimal diurnal/seasonal variation. Cooling needed year-round.
Humidity	High (70-90%RH), exacerbates heat sensation, inhibits evaporative cooling, causes material degradation.
Rainfall	Abundant (2500-3000 mm annually), concentrated in wet season. Requires robust water proofing.
Wind	South-westerly (wet season), North-westerly (dry season). Potential for natural ventilation, but urban limitations.
Solar Radiation	High intensity (4-5kWh/m²/day average), significant direct and diffuse components. Pervasive heat gain.
Sunshine Hours	4-8 hours daily average, lower during peak rainy season due to cloud cover.

4.2 Impact of Solar Radiation on Existing Residential Architecture

The pervasive solar radiation in Port Harcourt Metropolis exerts a profound impact on the performance of existing residential architecture, primarily leading to compromised indoor thermal comfort, increased energy consumption for cooling, and accelerated material degradation. These impacts are often exacerbated by architectural designs and material choices that do not adequately respond to the local climatic conditions.

Assessment of Thermal Performance in Typical Residential Buildings: Observations and studies indicate that many residential buildings in Port Harcourt exhibit suboptimal thermal performance, largely due to uncontrolled solar heat gain. The internal temperatures of these buildings frequently rise above comfortable levels, particularly during the day, creating an oppressive indoor environment. This is a direct consequence of building envelopes that are inefficient in blocking or mitigating solar radiation. For instance, roofs, which receive the most intense solar exposure, often lack adequate insulation or reflective properties, allowing significant heat transfer into the living spaces below (Nwuche & Daminabo, 2022). Similarly, walls, especially those facing east and west, absorb substantial solar energy, which then conducts into the interior. Windows, if not properly shaded or specified with low Solar Heat Gain Coefficient (SHGC) glass, act as major conduits for solar heat, directly radiating heat into rooms and contributing to glare (Okoro & Ohochuku, 2024).

The high humidity characteristic of Port Harcourt further compounds the thermal discomfort. Even if air temperatures are somewhat managed, the high moisture content in the air makes the environment feel muggy and uncomfortable, as the body's ability to cool itself through evaporative sweating is hindered. This combination of high temperature and humidity creates a challenging indoor climate that is difficult to alleviate without active cooling.

Analysis of Energy Consumption for Cooling: The direct and most significant consequence of poor thermal performance due to solar radiation is the escalated energy consumption for cooling. To achieve even a semblance of thermal comfort, residents are compelled to rely heavily on mechanical cooling systems such as air conditioners and fans. This reliance translates into substantial electricity bills, placing a considerable economic burden on households (Enwin & Okorosa, 2020; Uchechukwu, 2022). In a region where electricity supply is often unreliable and expensive, this increased demand for cooling not only strains household budgets but also contributes to the broader energy challenges faced by the metropolis. The operational energy consumed by these cooling systems represents a significant portion of the total energy footprint of residential buildings, contributing to greenhouse gas emissions and environmental degradation.

Observed Issues Related to Material Degradation and Indoor Discomfort: Beyond the immediate thermal and energy impacts, prolonged exposure to intense solar radiation leads to visible and structural degradation of building materials. The ultraviolet (UV) component of sunlight, combined with high temperatures, accelerates the aging process of exterior finishes. Paints fade, crack, and peel prematurely, requiring frequent repainting.

Roofing materials, particularly dark-colored ones, absorb significant heat, leading to thermal expansion and contraction cycles that can cause cracking, warping, and reduced lifespan (Nwuche & Daminabo, 2022). Wooden elements, if not properly treated and protected, are susceptible to rotting due to the combined effects of solar radiation and high humidity. Plastic components, such as window frames or pipes, can become brittle and discolored. This material degradation not only compromises the aesthetic appeal and structural integrity of buildings but also increases maintenance costs and reduces the overall economic lifespan of the property.

Furthermore, the uncontrolled solar penetration through windows often leads to excessive glare, making it difficult to perform visual tasks and contributing to eye strain. This also necessitates the use of curtains or blinds, which, while blocking glare, also reduce natural light, thereby increasing the need for artificial lighting during the day. In essence, the existing residential architecture in Port Harcourt, when not designed with adequate consideration for solar radiation, becomes a source of discomfort, high operational costs, and premature material failure, highlighting the urgent need for climate-responsive design interventions.

4.3 Evaluation of Current Design Practices and Material Choices

The evaluation of current design practices and material choices in Port Harcourt's residential architecture reveals a mixed landscape, where some traditional adaptations coexist with modern approaches that often fall short in effectively addressing the challenges posed by intense solar radiation. While there are instances of intuitive responses to the climate, a comprehensive and integrated climate-responsive design approach is not yet universally adopted.

Strengths and Weaknesses of Existing Architectural Responses to Solar Radiation: Historically, indigenous architecture in tropical regions developed passive strategies to cope with the climate. These often included thick walls, small openings, courtyards, and natural ventilation techniques. Some remnants of these principles can still be observed in older residential structures in Port Harcourt, such as the use of verandas and overhang in roofs that provide some degree of shading. However, the rapid urbanization and the adoption of contemporary architectural styles, often influenced by Western aesthetics, have led to a departure from these climate-appropriate designs. Many modern residential buildings in Port Harcourt exhibit characteristics that exacerbate solar heat gain, including:

- **Suboptimal Orientation:** While the ideal orientation for minimizing solar heat gain in tropical climates is to align the longest axis of the building along the east-west direction, many residential buildings in Port Harcourt are constructed without strict adherence to this principle. This often results in large east and west-facing facades that are exposed to intense low-angle solar radiation during critical periods of the day, leading to significant heat ingress (Enwin & Okorosa, 2020; Okoro & Ohochuku, 2024).
- **Inadequate Shading:** Despite the high solar intensity, many buildings lack effective external shading devices such as appropriately sized overhangs, vertical fins, or louvers. Windows are often left unprotected, allowing direct solar radiation to penetrate the interior, causing glare and overheating. While some buildings may have small eaves, these are often insufficient to provide comprehensive shading throughout the day and year (Nwuche & Daminabo, 2022).
- **Limited Natural Ventilation:** While the climate of Port Harcourt offers potential for natural ventilation, many residential designs do not fully optimize cross-ventilation or stack effect. Window placements may not facilitate effective air flow, and internal layouts can obstruct air movement. In high-density urban areas, the effectiveness of wind-driven ventilation can also be limited due to obstructions from adjacent buildings (Enwin & Samuel, 2021).

Common Building Materials and Their Thermal Properties: The predominant building materials used in residential construction in Port Harcourt include concrete blocks for walls, reinforced concrete for slabs and roofs, and various roofing materials such as corrugated iron sheets or concrete. The thermal properties of these materials significantly influences the building's response to solar radiation:

- **Concrete Blocks and Slabs:** Concrete is a material with high thermal mass. While high thermal mass can be beneficial in moderating temperature swings by absorbing heat during the day and releasing it at night, its effectiveness in a hot and humid climate like Port Harcourt depends heavily on proper ventilation to purge the stored heat. Without adequate night-time cooling, the heat absorbed by concrete during the day can be re-radiated into the interior, contributing to discomfort (Nwuche & Daminabo, 2022).
- **Roofing Materials:** Corrugated iron sheets are common due to their cost-effectiveness and ease of installation. However, these materials have low thermal mass and can heat up rapidly under solar radiation, transferring heat quickly into the building. Concrete roofs, while possessing higher thermal mass, also absorb significant solar energy if not properly insulated or treated with reflective coatings. Many roofs in Port Harcourt lack sufficient insulation, leading to substantial heat gain through the roof (Nwuche & Daminabo, 2022).

- **Wall Finishes:** Cement plaster is a common finish for external walls. While some buildings utilize light-colored finishes, which can reflect solar radiation and reduce heat absorption, the widespread adoption of highly reflective, cool-colored paints is not yet universal. Studies suggest that using white or light-colored external wall finishes can significantly reduce cooling energy consumption (Enwin & Okorosa, 2020; Okoro & Ohochuku, 2024).
- **Glazing:** Windows are often single-glazed and lack specialized coatings to reduce solar heat gain. This allows a large amount of solar radiation to penetrate the interior, contributing to overheating and glare. The window-to-wall ratio (WWR) is also a critical factor; large window areas, especially on exposed facades, can lead to excessive heat gain (Enwin & Okorosa, 2020).

Extent of Passive and Active Solar Design Integration: The integration of passive and active solar design strategies in Port Harcourt's residential architecture is currently limited and often fragmented. While there is a growing awareness of energy efficiency, its systematic application in design and construction is not yet a standard practice. Passive design elements, such as optimized orientation, effective shading, and natural ventilation, are often either overlooked or implemented without a comprehensive understanding of their climatic performance. Thermal insulation, a crucial component for reducing heat gain through the building envelope, is largely absent in many residential buildings, primarily due to perceived high costs and maintenance difficulties (Enwin & Okorosa, 2020).

Active solar systems, particularly photovoltaic (PV) panels for electricity generation, are gaining traction, driven by the unreliable grid electricity supply (Uchechukwu, 2022). However, their integration is often an afterthought, installed on existing buildings without optimal orientation or seamless architectural integration. While this provides a solution to power supply issues, it may not fully capitalize on the energy-saving potential that could be achieved through integrated design. Solar water heating systems are less common in residential settings compared to PV systems. The overall picture suggests that while the potential for climate-responsive design is immense in Port Harcourt, there is a significant gap between current practices and the optimal application of passive and active solar strategies to mitigate the effects of solar radiation and enhance building performance.

4.4 Proposed Climate-Responsive Design Strategies

Based on the analysis of Port Harcourt's climatic profile and the evaluation of current architectural practices, it is evident that a comprehensive and integrated approach to climate-responsive design is essential for mitigating the adverse effects of solar radiation on residential architecture. The proposed strategies aim to enhance thermal comfort, reduce energy consumption for cooling, and promote the long-term sustainability of buildings in the metropolis. These strategies encompass optimized building orientation, effective shading, enhanced natural ventilation, strategic use of thermal mass, judicious material selection, and the integration of active solar systems.

Optimized Building Orientation and Form: The fundamental step in climate-responsive design for Port Harcourt is to orient buildings to minimize exposure to intense solar radiation, particularly from the east and west. The longest axis of residential buildings should ideally be oriented along the east-west direction (Enwin & Okorosa, 2020; Okoro & Ohochuku, 2024). This minimizes the surface area exposed to the low-angle, high-intensity morning and afternoon sun. Conversely, the shorter facades, facing north and south, will receive less direct solar radiation throughout the day. While the sun is high in the sky at mid day, these facades are easier to shade effectively. Building forms should also be considered; compact forms with minimal surface area-to-volume ratios can reduce overall heat gain. Where possible, internal layouts should place less frequently occupied or heat-generating spaces (e.g., utility rooms, bathrooms, stairwells) on the east and west sides to act as thermal buffers.

Effective Shading Devices: Comprehensive external shading is paramount to prevent solar radiation from reaching the building envelope and interior spaces. A multi-layered approach to shading is recommended:

- **Overhangs:** Generous horizontal overhangs should be incorporated above all windows and exposed walls, particularly on the north and south facades, to block high-angle sun. The depth of these overhangs should be calculated based on the sun's angles in Port Harcourt to provide effective shading during peak solar hours (Nwuche & Daminabo, 2022; Okoro & Ohochuku, 2024).
- **Vertical Fins/Louvers:** For east and west-facing facades, vertical fins or louvers are crucial to block the low-angle sun. These can be fixed or adjustable, allowing for dynamic control over solar penetration and daylighting. Consideration should be given to integrating these elements aesthetically into the architectural design.
- **Vegetation:** Strategic landscaping with deciduous trees can provide effective seasonal shading, particularly on the east and west sides. Trees can also help cool the surrounding microclimate through evapo-transpiration, further reducing ambient temperatures around the building (Nwuche & Daminabo,

2022).

- **Recessed Openings and Balconies:** Designing windows and doors to be recessed within the wall plane or incorporating deep balconies can inherently provide self-shading, reducing direct solar exposure.

Enhanced Natural Ventilation Techniques: Maximizing natural air flow is critical for thermal comfort in Port Harcourt's humid climate. Design strategies should facilitate both cross-ventilation and stack effect:

- **Cross-Ventilation:** Ensure that rooms have openings on opposite walls to allow for continuous air flow. Window and door placements should be carefully considered to create clear pathways for air movement through the interior spaces. Internal partitions should be designed to be permeable (e.g., with high-level openings, louvers) to avoid obstructing air flow (Enwin & Okorosa, 2020).
- **Stack Effect:** Incorporate design features that promote the stack effect, such as high-level openings (e.g., clerestory windows, roof vents, solar chimneys) to allow hot air to escape, drawing in cooler air from lower-level openings. This is particularly effective during periods of low wind speed (Enwin & Samuel, 2021).
- **Building Spacing and Layout:** In urban planning, ensuring adequate spacing between buildings can facilitate wind flow and prevent mutual shading that might hinder natural ventilation. Courtyards and open-plan layouts within individual residences can also enhance air circulation (Okoro & Ohochuku, 2024).

Strategic Use of Thermal Mass and Insulation: The judicious application of thermal mass and insulation is vital for moderating indoor temperatures and reducing heat gain:

- **Thermal Mass:** While Port Harcourt has a hot climate, materials with high thermal mass (e.g., concrete, brick) can be beneficial if properly managed. They can absorb heat during the day and release it slowly at night. However, it is crucial to ensure effective night-time ventilation to purge the stored heat, preventing it from re-radiating into the interior during the cooler hours (Nwuche & Daminabo, 2022). This means combining heavy construction with effective ventilation strategies.
- **Insulation:** Robust insulation of the building envelope, particularly the roof and external walls, is essential to resist heat transfer from the exterior to the interior. For roofs, a double roof system with a highly reflective outer layer and insulation between the layers is highly recommended to significantly reduce heat ingress (Nwuche & Daminabo, 2022). Similarly, insulating external walls can drastically reduce cooling loads. While perceived as expensive, the long-term energy savings and enhanced comfort justify the initial investment (Enwin & Okorosa, 2020).

Judicious Material Selection and Surface Treatments: The choice of building materials and their surface treatments directly impacts solar heat absorption and reflection:

- **Reflective Surfaces:** Prioritize light-colored and highly reflective materials for exterior surfaces, especially roofs and walls. White or light-colored paints and cool roof coatings can significantly reduce solar heat absorption, leading to lower surface temperatures and reduced heat transfer into the building (Enwin & Okorosa, 2020; Okoro & Ohochuku, 2024).
- **Low U-value Materials:** Select walling materials with low U-values (thermal transmittance) to minimize heat conduction. Materials like Perlite plaster, which has a lower thermal transmittance value compared to traditional cement screed, should be considered (Enwin & Okorosa, 2020).
- **High-Performance Glazing:** For windows, utilize glazing with a low Solar Heat Gain Coefficient (SHGC) to reduce the amount of solar heat entering the building. Double glazing with a low-emissivity coating can further enhance thermal performance by reducing both heat gain and heat loss (though heat gain is the primary concern in Port Harcourt).
- **Durable Materials:** Given the high humidity and rainfall, select materials that are resistant to moisture, mold, and degradation from UV radiation to ensure long-term durability and reduce maintenance needs (Nwuche & Daminabo, 2022).

Integration of Active Solar Systems: While passive strategies reduce energy demand, active solar systems can meet the remaining energy needs efficiently and sustainably:

- **Photovoltaic (PV) Systems:** Rooftop-mounted or building-integrated PV systems should be encouraged for electricity generation. Given the high solar insulation in Port Harcourt and the unreliable grid supply, PV systems offer a viable solution for reducing reliance on conventional energy sources and lowering electricity bills (Uchechukwu, 2022; Wariboko, 2019).

Proper orientation and tilt of PV panels are crucial for maximizing energy yield.

Solar Water Heating (SWH) Systems: SWH systems can significantly reduce the energy required for domestic hot water. These systems are highly efficient in Port Harcourt's sunny climate and can be integrated neither into the roof design nor as standalone units (Wariboko, 2019).

By integrating these proposed climate-responsive design strategies, residential architecture in Port Harcourt Metropolis can transform from being a source of discomfort and high energy consumption to a model of thermal comfort, energy efficiency, and environmental sustainability. This holistic approach, combining passive and active measures, is essential for creating resilient and livable urban environments in the face of a challenging tropical climate.

5. Conclusion and Recommendations

5.1 Conclusion

This comprehensive investigation into the effects of solar radiation on residential architecture in Port Harcourt Metropolis has underscored the critical interplay between climatic factors and building performance in tropical environments. The study has systematically analyzed the unique climatic characteristics of Port Harcourt, revealing a consistently hot and humid environment with significant solar radiation throughout the year. This pervasive solar insulation, whether direct or diffuse, poses substantial challenges for residential buildings, leading to undesirable heat gain, compromised indoor thermal comfort, and escalated energy consumption for mechanical cooling.

Our assessment of current architectural practices in the metropolis indicates that while some traditional adaptations exist, a holistic and integrated climate-responsive design approach is not yet a standard. Many contemporary residential buildings in Port Harcourt are designed without adequate consideration for optimal orientation, effective external shading, or enhanced natural ventilation. Furthermore, the widespread use of materials with poor thermal performance and the general lack of robust insulation exacerbate the problem, contributing to thermally inefficient buildings that are heavily reliant on energy-intensive cooling systems. This reliance not only burdens households with high utility costs but also contributes to the broader energy challenges and environmental footprint of the region. Crucially, this research has highlighted that the adverse effects of solar radiation extend beyond immediate thermal discomfort and energy costs, impacting the long-term durability and aesthetic integrity of building materials. The degradation of external finishes and structural components due to prolonged solar exposure necessitates more frequent maintenance and reduces the overall lifespan of residential properties.

In response to these challenges, the study has proposed a suite of integrated climate-responsive design strategies tailored for Port Harcourt's residential architecture. These strategies emphasize a multi-faceted approach, beginning with fundamental considerations such as optimizing building orientation to minimize solar exposure on critical facades. The implementation of effective external shading devices, including generous overhangs and vertical fins, is paramount to intercept solar radiation before it enters the building. Enhancing natural ventilation through strategic window placement for cross-ventilation and the utilization of the stack effect is vital for promoting air flow and dissipating internal heat. The judicious use of thermal mass, coupled with robust insulation for roofs and walls, is essential for moderating indoor temperature swings and reducing heat transfer. Furthermore, the selection of materials with high reflectivity and low thermal transmittance, along with the integration of active solar systems like photovoltaic panels and solar water heaters, offers significant potential for reducing energy demand and harnessing renewable energy sources.

In conclusion, the findings of this study unequivocally demonstrate that solar radiation is a dominant climatic factor significantly impacting residential architecture in Port Harcourt Metropolis. Addressing these impacts requires a deliberate shift towards climate-responsive design principles that are integrated from the initial stages of planning and construction. By adopting the proposed passive and active solar strategies, residential buildings in Port Harcourt can achieve enhanced thermal comfort, substantial energy savings, improved material durability, and contribute significantly to the city's sustainable development goals. This research provides a foundational understanding and practical guidance for creating a more resilient, energy-efficient, and livable built environment in this tropical urban context.

5.2 Recommendations for Future Research

This study, while comprehensive in its literature-based approach, opens several avenues for future research to further deepen the understanding and implementation of climate-responsive design in Port Harcourt Metropolis and similar tropical urban environments:

1) **Empirical Performance Monitoring:** Future research should involve empirical studies through the long-term monitoring of thermal performance and energy consumption in existing and newly constructed residential buildings in Port Harcourt. This would involve deploying sensors to collect real-time data on indoor air temperature, relative humidity, surface temperatures, and energy use. Such

data would provide quantitative evidence of the effectiveness of various design strategies and validate the theoretical findings of this study.

2) **Cost-Benefit Analysis of Proposed Strategies:** A detailed economic analysis, including a comprehensive cost-benefit assessment, of implementing the proposed passive and active solar design strategies is crucial. This research could quantify the initial investment costs versus the long-term operational savings (e.g., reduced electricity bills) and environmental benefits (e.g., carbon emission reductions). Such an analysis would provide compelling arguments for developers, home owners, and policymakers to adopt these strategies.

3) **Socio-Cultural Factors and User Behavior:** Investigate the socio-cultural factors and occupant behavior that influence the adoption and effectiveness of climate-responsive design strategies. This could involve surveys and interviews with residents to understand their perceptions of thermal comfort, their energy consumption habits, and their willingness to embrace sustainable building practices. Understanding these human dimensions is vital for successful implementation.

4) **Material Performance under Local Conditions:** Conduct experimental research on the thermal and durability performance of various building materials, both traditional and modern, under the specific climatic conditions of Port Harcourt. This could involve laboratory testing and outdoor exposure tests to assess their U-values, solar absorptance, and resistance to degradation from humidity and solar radiation.

5) **Policy and Regulatory Frame works:** Research into the existing policy and regulatory frame works governing building design and construction in Port Harcourt and Nigeria. This would involve identifying gaps and proposing specific policy interventions, incentives, and building codes that can effectively promote and enforce climate-responsive and energy-efficient building practices.

6) **Urban Microclimate Studies:** Conduct detailed urban microclimate studies within Port Harcourt to understand how urban morphology, building density, and landscaping influences local temperatures, wind patterns, and solar access. This research could inform urban planning guidelines for creating cooler and more comfortable outdoor and indoor environments.

7) **Impact of Climate Change Projections:** Investigate how projected climate change scenarios (e.g., increased temperatures, altered rainfall patterns) might impact the effectiveness of current and proposed design strategies. This would involve climate modeling and adaptation strategies to ensure the long-term resilience of residential architecture in Port Harcourt.

5.3 Practical Recommendations

Based on the findings of this study, the following practical recommendations are put forth for architects, developers, home owners, and policymakers in Port Harcourt Metropolis to mitigate the adverse effects of solar radiation and enhance the sustainability of residential architecture:

For Architects and Designers:

1) **Prioritize Climate Analysis:** Conduct thorough climate analysis at the initial design stage, specifically focusing on solar paths, wind patterns, temperature, and humidity, to inform fundamental design decisions. Utilize bioclimatic charts and tools to understand comfort zones and design responses.

2) **Optimize Building Orientation:** Design residential buildings with their longest facades oriented along the north-south axis to minimize exposure to the intense low-angle sun from the east and west. This is the most cost-effective passive strategy.

3) **Integrate Comprehensive Shading:** Incorporate generous external shading devices for all windows and exposed walls. This includes appropriately sized horizontal overhangs for north and south facades, and vertical fins or louvers for east and west facades. Consider integrating vegetation for additional shading and microclimate cooling.

4) **Maximize Natural Ventilation:** Design for effective cross-ventilation by strategically placing openings on opposite walls within rooms. Utilize the stack effect by incorporating high-level vents or openings to allow hot air to escape. Ensure internal layouts do not obstruct air flow.

5) **Specify High-Performance Materials:** Select building materials with favorable thermal properties. Prioritize light-colored and highly reflective exterior finishes for roofs and walls to reduce solar heat absorption. Use materials with good thermal mass in conjunction with night-time ventilation. For glazing, specify windows with low Solar Heat Gain Coefficient (SHGC).

6) **Incorporate Insulation:** Advocate for and integrate robust thermal insulation in roofs and external walls. While it may increase initial costs, the long-term energy savings and enhanced thermal comfort

provide significant returns.

7) **Integrate Active Solar Systems:** Design for the seamless integration of photovoltaic (PV) panels for electricity generation and solar water heating (SWH) systems. Consider building-integrated photovoltaic's (BIPV) for aesthetic and functional benefits.

For Developers and Builders:

1) **Invest in Sustainable Practices:** Recognize the long-term economic and environmental benefits of sustainable building practices. Invest in training for construction workers on climate-responsive building techniques and the proper installation of energy-efficient components.
2) **Source Local and Sustainable Materials:** Prioritize the use of locally sourced and environmentally friendly building materials that are suited to the tropical climate and have good thermal properties. Explore innovative local materials that can enhance thermal performance.
3) **Quality Control:** Ensure high standards of construction quality, particularly in sealing the building envelope to prevent unwanted air infiltration and moisture ingress, which can compromise thermal performance and lead to material degradation.

For Home owners and Residents:

1) **Understand Your Home's Performance:** Be aware of how your home responds to the climate. Simple actions like opening windows at night for cooling and closing them during the day, or utilizing curtains/blinds, can make a difference.
2) **Consider Retrofits:** For existing homes, consider retrofitting measures such as adding external shading, applying reflective coatings to roofs, improving insulation, and installing energy-efficient windows to enhance thermal comfort and reduce energy bills.
3) **Embrace Renewable Energy:** Explore the possibility of installing small-scale PV systems or solar water heaters to reduce reliance on grid electricity and lower utility costs.

For Policy makers and Regulatory Bodies:

1) **Develop and Enforce Green Building Codes:** Implement and rigorously enforce building codes that mandate climate-responsive design principles, energy efficiency standards, and the use of sustainable materials for all new residential constructions.
2) **Provide Incentives:** Introduce financial incentives, such as tax breaks, subsidies, or low-interest loans, for developers and home owners who adopt green building practices and integrate renewable energy systems.
3) **Promote Research and Education:** Fund further research into climate-responsive design specific to Port Harcourt and establish educational programs for architects, builders, and the public on the benefits and implementation of sustainable building practices.
4) **Integrate into Urban Planning:** Incorporate climate-responsive design principles into urban master plans, including guidelines for building orientation, density, and green spaces to create a more comfortable and sustainable urban microclimate.

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Study and Reliability Evaluation of High-Performance Fiber-Reinforced Sealing Materials for New Energy Vehicles

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Abstract

The rapid development of the new energy vehicle industry has imposed stringent requirements on the reliability of core systems. As a key component of battery, motor, and electronic control systems, sealing materials directly affect the safety and service life of the entire vehicle. Traditional sealing materials have obvious shortcomings in high-temperature resistance, electrolyte corrosion resistance, and long-term aging stability, making them difficult to adapt to the complex working conditions of new energy vehicles. Fiber-reinforced composites, with their excellent mechanical properties and environmental adaptability, have become an important direction to break through the bottlenecks of traditional materials. The technical accumulation of Qingdao Eager High-Precision Plastic and Rubber Co., Ltd in die-cutting processing, precision molding, and polymer material modification provides a practical basis for the development of high-performance sealing materials. Its experience in material interface bonding, molding process optimization, and reliability testing can support the full-process research and development of fiber-reinforced sealing materials from formula design to practical application. Based on the sealing needs of new energy vehicles, this study combines precision processing technology and material modification experience to develop high-performance fiber-reinforced sealing materials suitable for key systems. Through performance testing and system reliability evaluation, it reveals the correlation mechanism between material properties and system stability, providing theoretical and practical support for the upgrading of new energy vehicle sealing technology.

Keywords: new energy vehicles, fiber-reinforced sealing materials, material development, system reliability, die-cutting processing, precision molding, polymer materials, performance testing, aging resistance, high-temperature resistance, corrosion resistance, sealing performance, reliability evaluation, formula optimization, process parameters

1. Research Foundation of High-Performance Fiber-Reinforced Sealing Materials

1.1 Performance Requirements for New Energy Vehicle Sealing Materials

The battery, motor, and electronic control systems of new energy vehicles have different and strict performance requirements for sealing materials. As the energy core, the battery system operates in a complex environment. The sealing materials need to have high-temperature resistance to adapt to temperature fluctuations of -40~150°C, and also need to be resistant to electrolyte corrosion to prevent safety hazards caused by electrolyte leakage. In addition, they must have low gas permeability to avoid gas exchange affecting battery performance. The motor system is the key to power output. The sealing materials need to be oil-resistant to resist the erosion of internal lubricating oil, wear-resistant to cope with friction during high-speed operation, and resistant to vibration fatigue to maintain the sealing effect during continuous vibration of the vehicle. The electronic control system is responsible for the power control of the vehicle. The sealing materials need to have good insulation to ensure circuit safety, resist damp-heat aging to adapt to long-term use under different humidity and temperature

conditions, and maintain dimensional stability to ensure the accuracy of the sealing structure.

1.2 Selection Basis of Fiber-Reinforced Materials

In terms of the selection of fiber-reinforced materials, it is necessary to comprehensively consider the type of reinforcing fibers, the matching of matrix materials, and the feasibility of existing processes. The selection of reinforcing fiber types needs to compare the mechanical properties and costs of glass fibers, carbon fibers, aramid fibers, etc. Glass fibers have low cost but relatively moderate mechanical properties; carbon fibers have excellent mechanical properties but high cost; aramid fibers have outstanding performance in temperature resistance. It is necessary to balance performance and cost according to actual needs. The matching of matrix materials is crucial. The interface bonding between rubber, resin and other matrices and fibers is highly required. Good interface bonding can effectively transfer stress and improve the overall performance of the composite material. Poor bonding may lead to a decline in material performance. The feasibility of existing processes also needs to be considered. With reference to the adaptability of die-cutting processing and precision molding technology to material forms, Qingdao Eager High-Precision Plastic and Rubber Co., Ltd has relevant practices in die-cutting processing and precision molding, and its experience can be used to judge whether fiber-reinforced materials can adapt to existing production processes, ensuring the smooth transformation of materials from research and development to production.

2. Preparation Process of High-Performance Fiber-Reinforced Sealing Materials

2.1 Formula Design and Optimization

In the process of formula design and optimization of high-performance fiber-reinforced sealing materials, it is necessary to combine the performance requirements of the material application scenarios and systematically carry out experiments on fiber content, addition of composite additives, and ratio optimization. For fiber content, gradient experiments of 10%~30% are set to explore the influence of different fiber proportions on material strength (Zhang, H., Li, X., & Wang, Y., 2021). The selection of this range not only considers the effectiveness of the fiber reinforcement effect but also refers to the common proportion of composite materials in similar die-cutting processing, ensuring that the material has sufficient mechanical properties without reducing processing performance due to excessively high fiber proportion. The addition of composite additives is the key to improving the aging resistance of the material. The selection of antioxidants needs to match the service temperature range of the material to cope with the high-temperature environment of the three electric systems of new energy vehicles. Toughers need to improve the toughness of the material without significantly reducing its strength, reducing the risk of brittle fracture caused by vibration or temperature changes. By adjusting the types and proportions of the two, the aging resistance of the material can be accurately controlled. To efficiently determine the optimal ratio, the orthogonal experimental method is adopted, with fiber content, antioxidant dosage, toughener dosage, etc., as key variables, and the tensile strength, aging resistance, sealing performance of the material as evaluation indicators. Through the analysis of multiple sets of experimental data, the formula combination with the best comprehensive performance is selected, laying the foundation for the subsequent molding process.

2.2 Control of Molding Process Parameters

The precise control of molding process parameters directly affects the final performance of high-performance fiber-reinforced sealing materials. Molding, as a suitable process for this type of material, needs to focus on optimizing temperature, pressure, and time parameters. The temperature is set at 160~180℃, which can ensure the full melting or crosslinking of the matrix material, ensuring good bonding with fibers, and avoiding material degradation or damage to fiber performance due to excessively high temperatures. The pressure is controlled at 5~10MPa, which can promote the material to tightly fill the mold cavity, reduce internal pores, and improve the compactness of the material. The time parameter needs to be adjusted according to the material thickness and formula to ensure the sufficiency of the molding process. The uniformity of fiber dispersion is an important factor affecting the consistency of material performance, which is controlled by synergistically adjusting the stirring rate and molding process. In the stirring stage, an appropriate rate is used to ensure the uniform distribution of fibers in the matrix, avoiding agglomeration. During the molding process, reasonable pressure transmission is used to further reduce local aggregation of fibers. With reference to the experience in controlling material uniformity in precision molding technology, the performance stability of all parts of the material is ensured. The verification of process stability is the premise for mass production. Through the performance testing of multiple batches of products, the deviation range of indicators such as mechanical properties and sealing performance is analyzed, ensuring that the fluctuation of material performance in large-scale production is within an acceptable range, meeting the consistency requirements of new energy vehicle seals. This process can draw on the quality control methods in the production of related materials to ensure the reliability and repeatability of the process.

3. Performance Testing and Analysis of Sealing Materials

3.1 Basic Performance Testing

Basic performance testing is a core link to evaluate whether high-performance fiber-reinforced sealing materials meet the application requirements of new energy vehicles, which needs to carry out systematic testing focusing on mechanical properties and sealing performance. In terms of mechanical properties, the tensile strength needs to reach ≥15MPa. This indicator refers to the static and dynamic stress requirements of new energy vehicle seals during assembly and use, ensuring that the material does not break under long-term stress. The elongation at break is set to ≥200%, aiming to ensure that the material has sufficient elastic deformation capacity to adapt to the dimensional fluctuations of the three electric systems caused by temperature changes or vibration, avoiding gaps in the sealing interface. The hardness is controlled in the range of Shore A 60~80, which not only needs to meet the supporting strength during sealing to prevent permanent deformation caused by excessive compression but also ensure a certain degree of softness to fill the micro-roughness of the sealing surface. This range is consistent with the hardness characteristics of commonly used sealing materials in die-cutting processing of Qingdao Eager High-Precision Plastic and Rubber Co., Ltd, which can be compatible with existing assembly processes. In the sealing performance test, the compression set experiment is carried out under the condition of 150℃×70h, requiring the result to be ≤25%. This condition simulates the impact of long-term high-temperature operation of the battery system on the seals. Low permanent deformation can ensure that the material still maintains the initial sealing capacity after repeated compression. High-precision leakage detection equipment is used to simulate the gas or liquid penetration scenario under actual working conditions. This indicator is directly related to the prevention and control of safety risks such as battery electrolyte leakage and motor lubricating oil leakage, and is a direct reflection of the core function of sealing materials.

3.2 Environmental Adaptability Testing

Environmental adaptability testing focuses on the long-term performance stability of sealing materials under complex working conditions of new energy vehicles, verifying the durability of materials by simulating extreme environmental conditions. The high-temperature aging test places the material in a 150℃ thermal oxygen aging box for 1000h, requiring the strength retention rate to be ≥80%. This duration and temperature parameter refer to the design life and extreme working temperature of the new energy vehicle battery system. By testing the changes in tensile strength and hardness after aging, the ability of the material to resist thermal oxygen degradation is evaluated, ensuring that there is no significant performance attenuation in the long-term high-temperature environment. The medium corrosion resistance test is aimed at two typical media: battery electrolyte and motor lubricating oil. The material is soaked in them respectively to determine the mass change rate, which is required to be ≤5%. The electrolyte uses a carbonate-based mixture commonly used in new energy vehicles, and the lubricating oil uses synthetic grease adapted to the drive motor. By monitoring the swelling, dissolution, or embrittlement of the material, its chemical stability is verified — which is consistent with the experience of Qingdao Eager High-Precision Plastic and Rubber Co., Ltd in the medium resistance test of polymer materials, focusing on whether delamination occurs at the interface bonding due to medium penetration. The weather resistance test simulates the impact of sunlight when the vehicle is parked outdoors through 300h of ultraviolet aging. In addition to observing whether cracking, discoloration, and chalking occur in appearance, it is also necessary to detect the attenuation range of mechanical properties and sealing performance, ensuring that the material can still maintain basic functions under long-term light conditions, providing guarantee for the sealing reliability of new energy vehicles throughout their life cycle.

4. Evaluation of the Impact of Sealing Materials on System Reliability

4.1 Failure Mode Analysis

The failure of sealing materials is the result of the combined action of the material's own performance attenuation, external environmental erosion, and assembly stress, which needs to carry out multi-dimensional analysis combined with the actual working conditions of the three electric systems of new energy vehicles. From the material perspective, aging is one of the core reasons. With reference to the data of Qingdao Eager High-Precision Plastic and Rubber Co., Ltd in the aging resistance test of polymer materials, if the fiber-matrix interface aging occurs in high-performance fiber-reinforced sealing materials, the tensile strength may decrease by more than 30%, which may lead to the loss of elasticity of the seals. The residual stress generated during the assembly process will accelerate material fatigue, and micro-cracks may appear in the seals under vibration conditions, which is similar to the failure law of precision components caused by uneven stress distribution in die-cutting processing. The coupling effect of environmental erosion further aggravates the risk of failure. The synergistic effect of electrolyte penetration and high temperature in the battery system may cause the volume expansion rate of the sealing material to exceed 8% within 6 months. The combined effect of lubricating oil and vibration in the motor system may cause the wear amount of the seal to increase to 0.3mm/1000h, far exceeding the tolerance threshold.

The risk mapping of key systems needs to combine quantitative analysis of failure consequences. If the sealing failure of the battery pack leads to an electrolyte leakage rate exceeding 0.5mL/h, it may cause electrode short circuit, resulting in a local temperature rise of more than 200℃, triggering thermal runaway risks. According to industry data statistics, battery failures caused by sealing failure account for 15%~20% of the total failures of new energy vehicle battery systems, and 30% of them may develop into safety accidents. The sealing failure of the motor system will lead to a lubricating oil leakage rate exceeding 1mL/100h, resulting in poor bearing lubrication, an increase in operating noise by more than 15dB, and a decrease in motor efficiency by 5%~8%. At the same time, the intrusion of foreign objects may cause wear of the stator and rotor, and in extreme cases, cause motor jamming, directly affecting driving safety. If the electronic control system is invaded by moisture due to sealing failure, the insulation resistance may drop below 100MΩ, increasing the risk of circuit short circuit and causing malfunction of the control system.

Table 1.

Failure Type	**Key Data Indicators**
Fiber-matrix interface aging	Tensile strength decreased by >30%
Synergistic erosion of electrolyte and high temperature	Volume expansion rate >8% within 6 months
Composite wear of lubricating oil and vibration	Seal wear amount reaches 0.3mm/1000h
Electrolyte leakage caused by sealing failure	Leakage amount >0.5mL/h, local temperature rise >200℃

4.2 Reliability Verification Methods

Reliability verification needs to ensure the improvement effect of sealing materials on system reliability through accelerated tests simulating real working conditions and quantitative index evaluation. The accelerated life test adopts the combined stress test of temperature cycle and vibration. With reference to the cycle design in the product reliability test of Qingdao Eager High-Precision Plastic and Rubber Co., Ltd, the total number of cycles is set to 1000 times. During the test, the compression set, and leakage rate of the seals are tested every 200 cycles. Compared with traditional material data, the fatigue resistance of high-performance fiber-reinforced materials is verified.

The calculation of reliability indicators is centered on the Mean Time Between Failures (MTBF). Through the statistical analysis of failure data of 100 groups of samples, the Weibull distribution model is used for fitting. Data show that the MTBF of the battery system using the new sealing material can reach more than 8000h, which is 60% higher than that of traditional materials, meeting the expected target. The MTBF of the motor system has increased from 6000h of traditional materials to 9500h, with an increase of 58% (Liu, J., Chen, M., & Zhao, L., 2020), significantly reducing the maintenance frequency caused by sealing failure. The cost-benefit analysis needs to comprehensively consider the material cost and the whole-life cycle maintenance cost. Although the unit cost of the new material is 30%~50% higher than that of traditional rubber, due to the improvement of reliability, the maintenance cost of the battery system can be reduced by 40%, and the replacement frequency of the motor system can be extended from once every 2 years to once every 3.5 years. The overall life cycle cost is reduced by 25%~30%, which meets the balance demand of new energy vehicle manufacturers for cost and reliability.

Table 2.

Verification Item	**Key Data Indicators**	**Comparative Data (Traditional Materials)**
Accelerated life test	Compression set and leakage rate tested every 200 cycles	The leakage rate of ordinary rubber seals rises to 1×10^{-5} Pa·m³/s after 500 cycles
Material cost	The cost of new materials is 30%~50% higher than that of traditional rubber	Traditional rubber cost as the benchmark
Maintenance cost	Maintenance cost reduced by 40%	Traditional material maintenance cost as the benchmark
Replacement frequency	Replacement cycle extended from once every 2 years to once every 3.5 years	The replacement cycle of traditional materials is once every 2 years

5. Application Cases and Technical Optimization

5.1 Practical Application Verification

In the battery pack sealing component installation test, the lithium iron phosphate battery pack of Lucid New Energy Technology Co., Ltd. was selected as the application object. The new sealing material was used to replace the traditional nitrile rubber seal, and 1000 charge-discharge cycle tests were carried out. The test results showed that after the cycle, the compression set of the sealing component was 18%, the internal humidity of the battery pack was maintained below 35%. After disassembly, it was observed that there was no obvious peeling at the bonding interface between the fiber-reinforced sealing material and the battery pack shell, while the traditional material group had local micro-cracks, confirming the sealing retention ability of the new material under dynamic working conditions.

The bench test of the motor end cover seal was aimed at an 80kW permanent magnet synchronous motor. The oil seal component made of the new sealing material was installed and subjected to a continuous 5000h operation test. The results showed that after the test, the wear amount of the seal was 0.06mm, the motor lubricating oil leakage was only 0.3mL, and the motor efficiency retention rate was 96.5%. Through infrared thermal imaging monitoring, it was found that the new sealing material had better heat dissipation uniformity, and the temperature difference on the end cover surface was controlled within 3℃, while the traditional material group had a temperature difference of 7℃ due to local sealing failure, verifying its stability under long-term dynamic friction conditions.

Table 3.

Test Object	**Key Performance Indicators**	**Test Results of New Sealing Materials**
Battery Pack Sealing Component	Compression Set	18%
	Internal Humidity	≤35%
Motor End Cover Seal	Wear Amount	0.06mm
	Lubricating Oil Leakage	0.3mL

5.2 Technical Improvement Directions

Fiber-matrix interface modification aims to improve the peel strength of the material. The current interface peel strength of the material is 8.5N/mm. By introducing 2% KH-550 for surface pretreatment of fibers, the interface bonding energy can be increased by 30%, and the expected peel strength can reach more than 11N/mm. Experimental data show that after the modified material undergoes 150℃ thermal oxygen aging for 1000h, the peel strength retention rate increases from 72% to 85%, effectively alleviating the interface aging problem under high temperature. At the same time, drawing on the “gradient interface design” concept applied in the company’s tape products, introducing a transition layer between fibers and the matrix can further reduce stress concentration, extending the service life of the material in vibration fatigue tests by 40%.

The automation of the molding process focuses on reducing performance fluctuations caused by manual operations. At present, the performance deviation rate of manual molding process is ±6%. By introducing a fully automatic molding production line, the deviation rate can be controlled within ±2.5%. Specifically, robot automatic feeding is used instead of manual feeding, combined with real-time pressure feedback to adjust molding parameters, so that the density uniformity of the material is increased to 98.5% (Wang, S., Zhang, Y., & Li, J., 2022). Production data show that after automation transformation, the standard deviation of tensile strength of batch products decreases from 1.2MPa to 0.5MPa, and the qualified rate of sealing performance increases from 92% to 99%, significantly reducing the quality risk caused by process fluctuations and adapting to the large-scale production needs of new energy vehicle parts.

6. Conclusion

Based on the comprehensive experimental research and performance test results, the optimal formula of high-performance fiber-reinforced sealing materials suitable for new energy vehicles is as follows: fiber content 20%, antioxidant addition 1.5%, toughener addition 3%. Under this formula, the material’s tensile strength reaches 18MPa, elongation at break 250%, and Shore A hardness 70, meeting the basic performance index requirements. The molding process parameters are optimized as follows: molding temperature 170℃, pressure 8MPa, heat preservation and pressure maintaining time 15 minutes. Under these conditions, the fiber dispersion uniformity reaches more than 95%, the material density fluctuation range is controlled within ±0.02g/cm³, and the performance deviation rate of mass production is ≤3%, which is compatible with the process capabilities of

the existing die-cutting processing and precision molding equipment of Qingdao Eager High-Precision Plastic and Rubber Co., Ltd.

Through practical scenario verification and reliability testing, the high-performance fiber-reinforced sealing material has a significant effect on improving the reliability of new energy vehicle systems: in battery pack applications, after 1000 charge-discharge cycles, the mean time between failures of the battery system increases from 5000h to 8000h, with an increase of 60%; in the motor system, after 5000h of continuous operation, the wear amount of the seal is only 0.06mm, the lubricating oil leakage is reduced by 83%, the motor efficiency retention rate is increased by 5.3 percentage points, and the MTBF is increased from 6000h to 9500h, with an increase of 58%. Overall, the material reduces the failure rate of the three electric systems caused by sealing failure by more than 55%, significantly reducing safety risks and maintenance frequency.

In terms of industrialization feasibility, the raw material supply of the material is stable. After automation transformation, the existing molding and die-cutting processing equipment can realize large-scale production. The unit product cost is 40% higher than that of traditional materials, but the whole-life cycle maintenance cost is reduced by 30% (Wang, S., Zhang, Y., & Li, J., 2022), and the cost difference can be recovered within 2 years, which has economic feasibility. In terms of promotion suggestions, it is recommended to prioritize application in battery packs and drive motor systems of high-end new energy vehicle models, and gradually expand the market with the customer resources and technical reputation of Qingdao Eager High-Precision Plastic and Rubber Co., Ltd in the polymer material field. At the same time, continuous research and development should be carried out on the improvement directions of fiber-matrix interface modification and process automation, further increasing the peel strength of the material to more than 11N/mm and controlling the performance deviation rate within ±2.5%, so as to adapt to the sealing needs of more vehicle models and promote the upgrading of new energy vehicle sealing technology.

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