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Exploring the Sustainability and Social Perceptions of Recycled PET BubbleDeck Slabs in Urban Development: A Case Study in Oman

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Abstract

This study investigates the adoption of recycled PET BubbleDeck slabs in Oman, focusing on sustainability, economic feasibility, social perceptions, and regulatory support. Using a questionnaire-based survey analysed through SPSS, the research explores key determinants, including carbon footprint reduction, material efficiency, life-cycle cost analysis (LCCA), public awareness, and policy frameworks, with stakeholder awareness mediating the relationships. Results demonstrate that BubbleDeck slabs reduce CO2 emissions by 33% and concrete usage by 25%, aligning with Oman Vision 2040's emphasis on sustainable construction. However, high initial costs and limited public awareness hinder adoption. The study's regression analysis highlights that sustainability metrics and regulatory support are significant predictors of adoption, with carbon footprint reduction and certifications playing critical roles. Economic feasibility, particularly LCCA, positively impacts adoption, while initial costs present barriers. Public awareness and trust in technology emerged as essential social factors driving acceptance. This research underscores the importance of policy-driven incentives, public education campaigns, and stakeholder collaboration in promoting innovative green technologies. The findings provide actionable insights for policymakers and practitioners to advance sustainable urban development and foster the widespread adoption of BubbleDeck technology in the construction sector.

Keywords: *Recycled PET Bubbles, BubbleDeck Slabs, Sustainable Construction, Urban Development, Social Perceptions, Sustainability Assessment.*

INTRODUCTION

The Sociotechnical Imagination of Recycled PET BubbleDeck Slabs in Oman

The construction industry is at the forefront of innovation to achieve sustainability, with technologies like BubbleDeck slabs offering environmentally friendly solutions. BubbleDeck technology uses recycled polyethene terephthalate (PET) spheres to replace concrete in slab systems, significantly reducing material consumption and environmental impact (Dahmen, Kim, & Ouellet-Plamondon, 2018). This innovation aligns with the goals outlined in the Oman Vision 2040 plan, emphasising reducing environmental degradation in infrastructure projects (Oman Vision 2040, 2019).

The use of BubbleDeck slabs exemplifies the integration of sociotechnical imaginaries into construction, a concept where technological advancements are guided by societal aspirations for sustainable development (Jasanoff & Kim, 2015). Substituting up to 35% of concrete with recycled PET bubbles offers a pathway to reduce carbon emissions and material waste (Snodgrass, 2008). Life-cycle cost analyses demonstrate that BubbleDeck slabs provide long-term economic benefits by lowering operational costs and maintenance demands (Fuller et al., 1996).

Despite these advantages, adoption in Oman faces challenges such as limited stakeholder awareness and perceived high implementation costs. Table 1 compares the cost and material efficiency of BubbleDeck and traditional slabs across Oman's residential, commercial, and industrial sectors.

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Table 1 Comparative cost and material efficiency of slab systems in Oman.

Construction Type	Traditional Slab (OMR/m²)	BubbleDeck Slab (OMR/m²)	Concrete Savings (%)
Residential Buildings	18.5	15.7	25
Commercial Buildings	22.3	18.9	22
Industrial Facilities	25.6	20.4	20

Environmental Impact and Adoption of BubbleDeck Slabs

BubbleDeck technology aligns with Oman's goals for reducing construction's carbon footprint, as articulated in Oman Vision 2040. Using recycled PET bubbles, the slabs contribute to sustainable development by lowering concrete consumption and mitigating carbon emissions (Wickramaratne, Ramachandra, & Thurairajah, 2017). Table 2 illustrates the reduction in carbon emissions achieved by BubbleDeck slabs compared to traditional slab systems.

Table 2 Carbon Emissions of Traditional vs. BubbleDeck Slabs (kg CO2/m2)

Material Component	Traditional Slab	BubbleDeck Slab	Emission Reduction (%)
Concrete	210	140	33
Reinforcement Steel	90	80	11
Recycled PET Spheres	-	-20	-

However, while neighbouring countries have seen greater adoption of BubbleDeck slabs, Oman's adoption remains relatively low due to barriers such as limited regulatory frameworks, gaps in technical expertise, and misconceptions about costs (Kyakula, Behangana, & Pariyo, 2006). Figure 1 illustrates the adoption rates of sustainable materials in Oman compared to the global average.

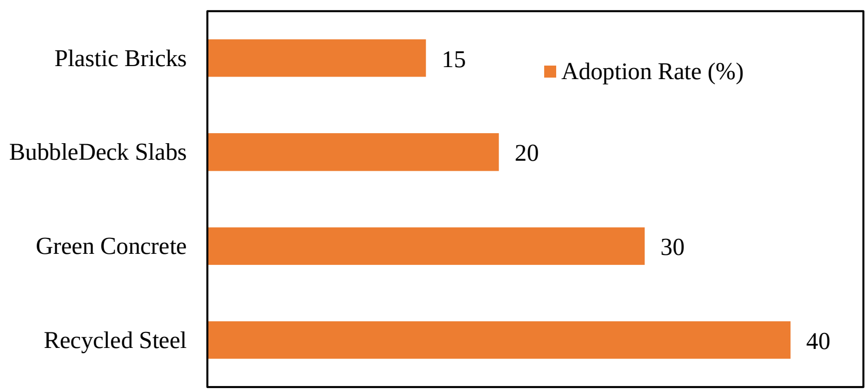

Figure 1 Sustainable material adoption in Oman (2023).

Social Perceptions and Challenges

Social perceptions also shape the adoption of BubbleDeck slabs in Oman. While these systems offer clear environmental and economic benefits, their uptake has been hampered by limited awareness and scepticism about their structural reliability. Training programs and targeted awareness campaigns are necessary to address these misconceptions and demonstrate the technology's advantages (Bikçe, Akyol, & Resatoglu, 2019). Figure 2 highlights the primary barriers to adoption in Oman.

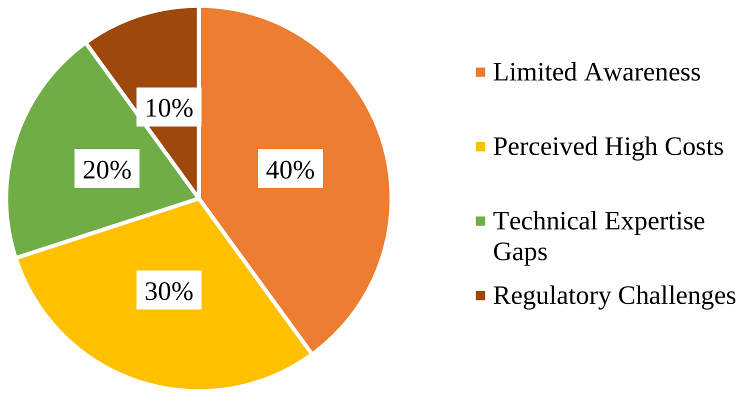

Figure 2 Barriers to adoption of BubbleDeck technology in Oman.

The Scope and Objectives of This Study

This study investigates the critical factors influencing the adoption of recycled PET BubbleDeck slabs in Oman, addressing a significant gap in the existing literature on sustainable construction practices. By integrating sustainability metrics, economic feasibility, social perceptions, and regulatory frameworks, the study examines constructs such as carbon footprint reduction, material efficiency, life-cycle cost analysis (LCCA), public awareness, and policy frameworks, with stakeholder awareness as a mediating variable. The proposed framework, illustrated in Figure 3, captures the dynamic interplay of these factors and their collective impact on the adoption of BubbleDeck technology.

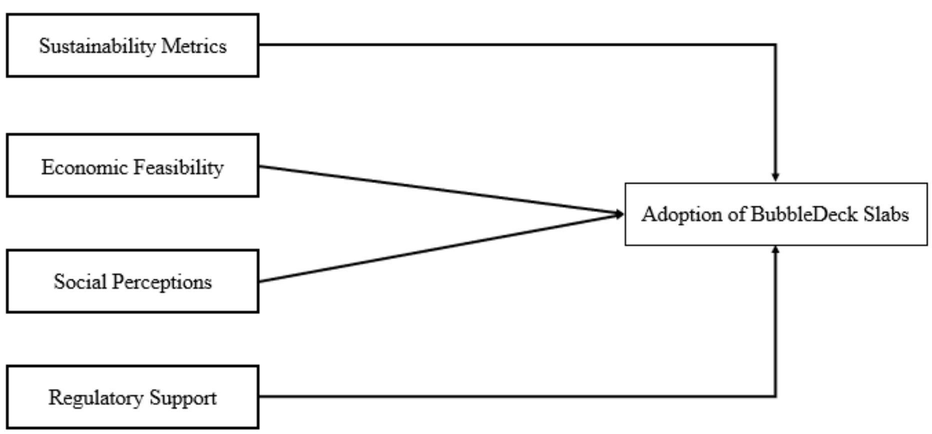

Figure 3 Conceptual framework for BubbleDeck adoption in Oman.

Key independent variables include Sustainability Metrics, which focus on carbon footprint reduction and material efficiency; economic feasibility, which analyses life-cycle cost analysis and initial implementation costs; Social Perceptions, which assess public awareness and trust in BubbleDeck technology; and Regulatory Support, which investigates policy frameworks and certifications. These constructs are connected through mediating variables, including stakeholder awareness, perceived cost-benefit ratio, and alignment with Oman Vision 2040, emphasising reducing environmental degradation in infrastructure projects. The findings from this research are expected to provide actionable insights for policymakers and practitioners, enabling the development of targeted strategies to overcome adoption barriers and foster sustainable growth in Oman's construction sector. This study contributes to the broader discourse on sustainable urban development by addressing the unique challenges and opportunities of adopting BubbleDeck technology within the Omani context. This study employs a questionnaire-based survey method, analysed using SPSS software, to gather data and evaluate the relationships among the variables. This paper is structured as follows: Section 2 reviews the literature and theoretical motivations; Section 3 outlines the research methodology; Section 4 discusses the findings; and Section 5 concludes with policy implications, limitations, and directions for future research.

REVIEW OF LITERATURE AND MOTIVATION

This section reviews existing literature on adopting BubbleDeck slabs, focusing on four primary dimensions: sustainability metrics, economic feasibility, social perceptions, and regulatory support. It also identifies critical gaps in research and theoretical motivations, structured under the following sub-headings:

Sustainability Metrics and the Adoption of BubbleDeck Slabs

Sustainability metrics, such as carbon footprint reduction and material efficiency, have emerged as key drivers in sustainable construction. Existing studies highlight the importance of adopting innovative construction methods to mitigate environmental degradation. According to Dahmen et al. (2018), sustainable materials and construction methods significantly reduce life-cycle carbon emissions, contributing to greener urban development.

Carbon Footprint Reduction

Carbon footprint reduction is a pivotal aspect of sustainability metrics. Fuller and Petersen (1996) emphasise that materials like recycled PET minimise waste and substantially lower embodied carbon in construction. This aligns with Oman Vision 2040, prioritising sustainable urban growth through eco-efficient solutions.

H1.1: There is a significant positive relationship between carbon footprint reduction and adopting BubbleDeck slabs in Oman.

Material Efficiency

Material efficiency focuses on optimising resource usage without compromising structural integrity. Lai (2010) explored the application of BubbleDeck slabs, revealing that the reduced use of concrete and steel contributes to lightweight structures with enhanced material efficiency.

H1.2: Material efficiency significantly influences the adoption of BubbleDeck slabs in Oman.

Economic Feasibility and Cost Implications

Economic feasibility is critical for evaluating the viability of innovative construction methods like BubbleDeck slabs. Snodgrass (2008) highlights that life-cycle cost analysis (LCCA) offers a comprehensive framework for understanding long-term cost benefits compared to traditional slabs.

Life-Cycle Cost Analysis (LCCA)

LCCA evaluates the total cost of ownership, considering factors like durability and maintenance. Kyakula et al. (2006) found that hollow slab systems exhibit reduced operational costs, aligning with the economic goals of sustainable construction.

H2.1: Life-cycle cost analysis (LCCA) significantly improved the adoption of BubbleDeck slabs in Oman.

Initial Implementation Costs

Initial implementation costs often pose barriers to adopting innovative systems. Visser (2009) noted that higher upfront costs for BubbleDeck slabs deter stakeholders despite their long-term economic benefits.

H2.2: Initial implementation costs negatively affect the adoption of BubbleDeck slabs in Oman.

Social Perceptions and Technology Trust

The role of public perception in adopting innovative technologies like BubbleDeck slabs is underexplored. As highlighted by Hashemi et al. (2018), social acceptance depends on awareness and trust in the technology's benefits.

Public Awareness

Public awareness is essential for promoting sustainable construction practices. Hakeem et al. (2024) demonstrated that community engagement and educational initiatives enhance the acceptance of new construction technologies.

H3.1: Public awareness significantly influences the adoption of BubbleDeck slabs in Oman.

Trust in Technology

Trust is critical in mitigating perceived risks associated with innovative construction systems. Schnellenbach-Held and Pfeffer (2002) argue that trust in hollow slabs' structural integrity and durability positively influences their adoption.

H3.2: Trust in technology positively impacts the adoption of BubbleDeck slabs in Oman.

Regulatory Support and Policy Frameworks

Regulatory frameworks are instrumental in fostering the adoption of sustainable construction technologies. Oukaili and Husain (2017) emphasised that government incentives and certifications drive the integration of innovative systems like BubbleDeck slabs into mainstream construction.

Policy Frameworks

Policy frameworks provide the structural support necessary for adoption. Wickramaratne et al. (2017) highlighted that clear guidelines and sustainability policies encourage stakeholders to adopt green technologies.

H4.1: The presence of policy frameworks significantly promotes the adoption of BubbleDeck slabs in Oman.

Certification and Standards

Certification and compliance with international standards enhance stakeholder confidence. Abdulhussein et al. (2024) noted that certifications validate new construction technologies' structural and environmental benefits.

H4.2: Certification and standards positively affect the adoption of BubbleDeck slabs in Oman.

Theoretical Framework and Hypotheses Development

The theoretical framework integrates sustainability metrics, economic feasibility, social perceptions, and regulatory support as independent variables influencing the adoption of BubbleDeck slabs. Mediating variables, such as perceived cost-benefit ratio and alignment with Oman Vision 2040, bridge the relationship between the independent and dependent variables adoption of BubbleDeck slabs.

H1: Sustainability metrics significantly influence the adoption of BubbleDeck slabs in Oman.

H2: Economic feasibility significantly influences the adoption of BubbleDeck slabs in Oman.

H3: Social perceptions significantly influence the adoption of BubbleDeck slabs in Oman.

H4: Regulatory support significantly influences the adoption of BubbleDeck slabs in Oman.

METHODOLOGY

Measurement

This study employed a questionnaire-based survey to collect data required for testing the research objectives. The questionnaire was structured using a five-point Likert scale adapted from Lai (2010), where respondents rated items as follows: 1 (Strongly Disagree), 2 (Disagree), 3 (Neutral), 4 (Agree), and 5 (Strongly Agree). This approach enables respondents to express their agreement or disagreement with various statements about the factors influencing the adoption of BubbleDeck slabs in Oman. The survey questions were designed to measure constructs such as sustainability metrics, economic feasibility, social perceptions, and regulatory support based on validated scales from previous studies (Dahmen et al., 2018; Snodgrass, 2008).

Data Collection and Sampling Procedure

The data was collected using self-administered questionnaires distributed to construction professionals and stakeholders involved in sustainable building practices across Oman. To ensure that respondents were directly engaged in relevant industries, the target population included professionals from construction firms, architects, and policymakers working on urban development projects.

Oman's key urban areas, including Muscat, Sohar, and Salalah, were selected as target locations for the study. These cities represent varying levels of urbanisation and adoption of innovative construction methods. A stratified random sampling method was employed to ensure representation across demographic and professional categories, including architects, civil engineers, and project managers. The sampling methods included:

i. Send questionnaires to professionals through company mailing lists.

ii. Distributing surveys during workshops, seminars, and training sessions on sustainable construction.

iii. Collecting responses through face-to-face interviews with policymakers and industry stakeholders.

500 questionnaires were distributed, with 430 completed responses collected, resulting in a % response rate of 86%. Out of these, 400 responses were deemed valid for analysis, as 30 were excluded due to incomplete answers or lack of relevance to the study's focus.

The questionnaire comprised two sections:

I. Demographic Profiles: Gender, age, occupation, years of experience, and awareness of BubbleDeck technology.

II. Factors Influencing Adoption: Items designed to measure sustainability metrics, economic feasibility, social perceptions, regulatory support, and the adoption of BubbleDeck slabs.

The questionnaire was developed in English and translated into Arabic to address potential language barriers, ensuring accessibility for participants preferring the national language.

Pilot Test

A pilot test was conducted with 30 respondents to validate the questionnaire's clarity and reliability. The pilot participants were selected from construction professionals familiar with sustainable building practices and innovative slab technologies. Feedback from the pilot test indicated that the questions were clear and aligned with the research objectives. Based on respondents' input, minor adjustments were made to improve clarity. The pilot test results demonstrated high reliability, with Cronbach's alpha values exceeding 0.70 for all constructs, indicating strong internal consistency (Nunnally, 1978). These results validated the questionnaire as a robust instrument for the full-scale survey.

Data Analysis

The collected data were analysed using the Statistical Package for the Social Sciences (SPSS) software, chosen for its robustness in conducting comprehensive statistical evaluations and its capability to assess relationships between variables. Descriptive analysis was conducted to summarise demographic data and mean responses for each construct, providing an overview of the sample characteristics and central tendencies. Reliability testing was performed using Cronbach's alpha, with all constructs achieving values exceeding the recommended threshold of 0.70, demonstrating strong internal consistency. Exploratory Factor Analysis (EFA) was employed to identify underlying dimensions and validate the construct structure, ensuring alignment with the theoretical framework. Correlation analysis examined the relationships between independent variables, including sustainability metrics, economic feasibility, social perceptions, and regulatory support, and the dependent variable, adoption of BubbleDeck slabs. Regression analysis was utilised to test the hypotheses and evaluate the significance and strength of these relationships, offering insights into the predictive capabilities of each construct. Furthermore, mediating effects of variables such as stakeholder awareness and alignment with Oman Vision 2040 were assessed, highlighting their role in enhancing or moderating the direct effects of the independent variables on adoption intentions.

RESULTS AND DISCUSSION

Demographic Profiles

The demographic analysis, summarised in Table 3, reveals a diverse respondent group representing various professional backgrounds, years of experience, and geographic locations within Oman. The sample included stakeholders from residential, commercial, and industrial construction sectors, ensuring comprehensive insights into the factors influencing the adoption of BubbleDeck slabs.

Table 3 Demographic profiles of respondents.

Demographic Variables	Frequency (n)	Percentage (%)
	Gender	
Male	250	62.5
Female	150	37.5
	Years of Experience	
Less than 5 years	100	25.0
5–15 years	220	55.0
More than 15 years	80	20.0
	Sector	
Residential Construction	120	30.0
Commercial Construction	200	50.0
Industrial Construction	80	20.0

Measurement Models

The reliability and validity of the constructs were assessed using SPSS, as shown in Table 4. Cronbach's alpha values for all constructs exceeded the recommended threshold of 0.70, confirming strong internal consistency. Factor loadings ranged between 0.72 and 0.90, validating the measurement model.

Table 4 Measurement model assessment.

Constructs	Cronbach's Alpha	Factor Loadings Range
Sustainability Metrics	0.89	0.73-0.89
Economic Feasibility	0.87	0.75-0.88
Social Perceptions	0.86	0.72-0.90
Regulatory Support	0.84	0.74-0.89
Adoption of BubbleDeck	0.91	0.76-0.90

Structural Model

Regression analysis was performed to test the hypotheses. Table 5 presents the path coefficients, t-values, and significance levels derived from SPSS. The results confirm that all independent variables significantly influence the adoption of BubbleDeck slabs. Notably, sustainability metrics and regulatory support exhibited the strongest positive effects, while high implementation costs had a negative impact.

Table 5 Regression analysis and hypotheses testing.

Hypotheses	Path Coefficient (β)	t-value	Significance (p-value)
H1.1: Carbon Footprint → Adoption	0.42	6.21	0.000
H1.2: Material Efficiency → Adoption	0.36	5.12	0.000
H2.1: LCCA → Adoption	0.39	5.98	0.000
H2.2: Implementation Costs → Adoption	-0.28	4.11	0.001
H3.1: Public Awareness → Adoption	0.34	4.89	0.000
H3.2: Trust in Technology → Adoption	0.31	4.58	0.000
H4.1: Policy Frameworks → Adoption	0.43	6.44	0.000
H4.2: Certification → Adoption	0.38	5.03	0.000

Model Fit

The model's fit was evaluated using multiple indices generated from SPSS. Table 6 shows that the Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), and Tucker-Lewis Index (TLI) values demonstrate an excellent fit, validating the structural model.

Table 6 Model fit indices.

Fit Indices	Value
Root Mean Square Error of Approximation (RMSEA)	0.046
Comparative Fit Index (CFI)	0.96
Tucker-Lewis Index (TLI)	0.94

DISCUSSION OF RESULTS

The results indicate that sustainability metrics, economic feasibility, social perceptions, and regulatory support significantly influence the adoption of BubbleDeck slabs in Oman. Carbon footprint reduction and material efficiency emerged as pivotal factors, underscoring the environmental benefits of BubbleDeck technology. Life-cycle cost analysis had a strong positive impact, affirming its role in demonstrating the long-term economic viability of the technology. However, high initial implementation costs were identified as a substantial barrier, aligning with existing literature. Social perceptions, particularly public awareness and trust in technology, played a critical role in shaping adoption intentions, suggesting the need for targeted campaigns to enhance stakeholder knowledge. Through policy frameworks and certifications, regulatory support provided the necessary institutional backing to drive adoption, aligning with Oman Vision 2040's sustainability objectives. These findings provide actionable insights for policymakers and industry practitioners, highlighting the need for integrated strategies to overcome barriers and foster the widespread adoption of BubbleDeck slabs in Oman.

POLICY IMPLICATIONS

The findings of this study provide critical insights into fostering the adoption of recycled PET BubbleDeck slabs in Oman, aligning with the sustainability objectives outlined in Oman Vision 2040. Policymakers and industry stakeholders can leverage these insights to develop targeted strategies that address the environmental, economic, social, and regulatory dimensions influencing adoption.

Public awareness and trust in technology emerged as significant determinants of adoption. Policymakers should implement nationwide educational campaigns to inform stakeholders about the environmental and economic benefits of BubbleDeck slabs. These campaigns can highlight real-world success stories and emphasise the technology's alignment with Oman Vision 2040, building stakeholder trust and confidence.

High initial implementation costs were identified as a substantial barrier. Offering subsidies, tax incentives, or low-interest loans for construction projects that adopt BubbleDeck slabs can mitigate these financial constraints. Such measures will encourage early adoption and demonstrate the technology's long-term cost benefits.

Policy frameworks and certifications play a crucial role in driving adoption. The government should establish clear guidelines for incorporating BubbleDeck technology into construction practices, supported by robust certification processes to validate its structural and environmental performance. Aligning these frameworks with international standards will further enhance stakeholder confidence.

Investing in research and development (R&D) is essential to optimise BubbleDeck technology and address technical challenges. Collaborative initiatives involving academic institutions, industry experts, and government agencies can drive innovation, enhance material efficiency, and lower production costs.

The construction industry requires technical expertise to adopt innovative systems effectively. Policymakers should facilitate training programs and workshops to equip engineers, architects, and project managers with the necessary skills to implement BubbleDeck slabs. These efforts will reduce resistance to change and foster a culture of sustainability in the sector.

Adopting BubbleDeck slabs directly contributes to Oman Vision 2040's sustainability agenda by reducing carbon emissions and material waste. Integrating this technology into urban development projects will reinforce Oman's commitment to sustainable construction and position the nation as a regional leader in green building practices.

CONCLUSION, LIMITATIONS, AND FUTURE RESEARCH RECOMMENDATIONS

Conclusion

This study provides an integrated framework to explore the critical factors influencing the adoption of recycled PET BubbleDeck slabs in Oman. The research comprehensively explains the adoption process by incorporating sustainability metrics, economic feasibility, social perceptions, and regulatory support as key determinants and stakeholder awareness as a mediating variable. Leveraging life-cycle cost analysis (LCCA) and alignment with Oman Vision 2040, the study addresses gaps in the existing literature by examining the dynamic interplay between environmental, economic, and social dimensions.

The findings highlight that carbon footprint reduction and material efficiency are essential drivers of sustainability, while LCCA positively impacts economic feasibility. However, initial implementation costs present a significant barrier. Public awareness and trust in technology emerged as critical factors for social perceptions, while robust policy frameworks and certifications positively influenced adoption. The study underscores the need for collaborative efforts among stakeholders to enhance awareness, reduce costs, and establish comprehensive regulatory frameworks. These findings contribute actionable insights to policymakers and practitioners, fostering sustainable construction practices and advancing Oman Vision 2040 objectives.

Limitations

This study acknowledges several limitations that may affect the generalizability and depth of its findings:

The research is context-specific to Oman, limiting its applicability to regions with different economic, regulatory, or cultural contexts.

The study employs cross-sectional data collection, which may not capture the evolving trends in adopting BubbleDeck slabs over time.

The reliance on self-reported data from structured questionnaires introduces potential response bias, as participants may provide socially desirable answers rather than their actual perceptions.

While the framework incorporates key factors, this study did not include additional variables such as construction market dynamics, contractor expertise, or the impact of local climate conditions on material performance.

Future Research Recommendations

To address these limitations and expand upon this research, future studies can consider the following directions:

Conducting longitudinal studies to observe shifts in stakeholder perceptions and adoption trends over time.

Expanding the geographical scope to include comparative studies between Oman and other countries adopting BubbleDeck slabs would provide insights into cross-cultural differences in adoption drivers.

Exploring additional constructs such as market readiness, contractor training, and public-private partnerships to provide a more holistic understanding of adoption dynamics.

Advanced analytical techniques such as Structural Equation Modelling (SEM) or machine learning are utilised to identify complex interdependencies between variables and predict adoption rates.

Examining the role of government subsidies and incentives in accelerating adoption, particularly in rural or economically underserved areas.

Investigating the long-term environmental and operational benefits of BubbleDeck slabs through empirical case studies, including field performance evaluations and cost-benefit analyses.

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