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From Conventional Mining to Smart Materials: A Path to Eco-Friendly Construction for Green Consumerism and A Reduced Environmental Impact

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Abstract

The research highlights the importance of smart materials and how they are used in modern industries, particularly in construction sector. This study explores different smart construction materials and investigates how these smart materials influence consumer decisions with environmental health and sustainability as consumption goals. Further, it explores the degree of challenges faced while deploying the smart and recyclable material into ecosystem. Smart materials have diverse qualities that may be controlled by external elements such as temperature, magnetic fields, stress etc. This study employs a descriptive research approach. The study model was created to assess the impact of smart construction materials (input variable) on environmental health (outcome variable), with green consumerism goals serving as an intervening variable. A well-structured questionnaire was developed consisting questions on key variables such as awareness and use of smart construction materials, influence of smart materials on environmentally conscious users, and challenges faced by users in implementing smart materials in construction industry. The sample unit consist of consumers and contractors in Karnataka. The judgement sampling technique is used for data collection. The sample size used in the study for consumer survey is 384 and builder survey is 34. The data are analysed using the statistical tools viz., Chi square, ANOVA, correlation analysis, multiple regression and binary logistic regression. The result of the study will throw light on the level of awareness and influence of smart construction materials and augment green construction activities among the environmentally cautious users. The study may motivate the users of construction sector to make actionable decisions on usage of smart materials for environmentally sustainable future.

Keywords: *Environment Challenges, Green Consumerism, Recycling, Smart Materials, Sustainable Consumption*

1.0 Introduction

History of smart material traces back to roughly four and half thousand years ago where Egyptians built the Giza Pyramid using a material called 'lime mortars' that by nature is self-healing type at atomic level, meaning whenever cracks were developed this lime mortar reacted with atmospheric moisture and CO_2 in the air and started forming lime stone that grows inside the crack, thus healing itself[1]. Quartz was the first intelligent substance to be identified by scientists Pierre and Jacques Curie in 1880. Many of the problems encountered in daily life might be solved by smart materials such as self-healing cementitious material - repairs frequent cracks in the building industry[2] shape shifting metals makes building withstand earthquakes of lower magnitudes, transparent aluminium - stronger than glass and highly durable and electromagnetic shielding 'Piezoelectric Materials'.

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Construction related pollution has become major threat to global warming. Illegal and improper dumping is a prevalent issue. Smart, green and sustainable construction is the practise of employing environmentally and socially responsible and resource-efficient techniques throughout a building's life-cycle, from design to construction, operation, maintenance, restoration, and demolition, therefore avoiding detrimental environmental ramifications.

During 2009, the international construction sector released 5.7 billion tonnes of CO_2 emissions, accounting for 23% of all CO_2 pollutants released by all economic activity worldwide, with 60% of all CO_2 emissions from the building sector worldwide, China is the biggest producer[3]. In the backdrop of changing environmental health related consciousness, sustainable practices are required at each stage of construction, the recent trends indicated that the consumers are adapting varied measures to live more sustainably[1]. It is important to identify about awareness of different smart materials in use specifically in construction sector. It is important to know the roadblocks faced by users of smart construction materials in construction industry.

Objectives:

- To explore various smart materials used in construction sector, such as household, commercial, and public utility infrastructure.
- To study the influence of smart materials on consumer's decisions regarding environmental health and sustainability (green consumption) as their goal.
- To investigate the multidimensional challenges faced while deploying smart materials in construction sector and how to overcome them.
- To assess the willingness towards purchase of smart material in construction i.e. survey based intention action gap evaluation.

1.1 Intention and Action Gap assessment of Willingness

Human psychology research has revealed that attitude shape intentions, which then determine actions.

The Theory of Reasoned Action (TRA) and Theory of Planned Conduct (TPB) are based on the premise that intentions are affected by attitudes about social norms and behaviour which in turn affect outcome (action).

[a] Shifting sand: How consumer behaviour is embracing sustainability, Deloitte.

From Figure 2 it apparent that a consumer especially in choosing the smart, green and sustainable material for construction has to certainly cross all these internal and external constructs/variables. Crossing these many constructs sometimes one may gain momentum toward green consumerism or may lose intention toward green consumerism. The intention action gap gets reduced when there is harmony among all three constructs attitude, perceived norm and personal agency, thus promoting willingness and adoption of smart and sustainable construction material.

1.2 Green Consumerism

Green consumption is associated with ecological sustainability and sustainability consumer behaviour.

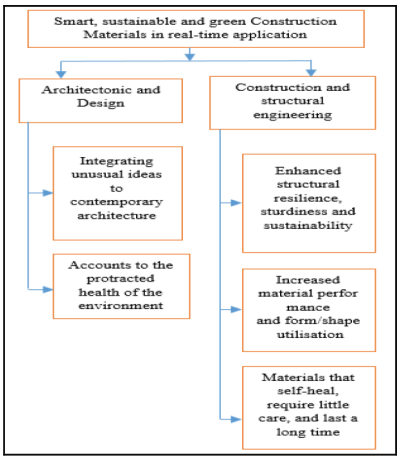


Figure 1. Smart materials real-time implications in construction sector.
Source: own

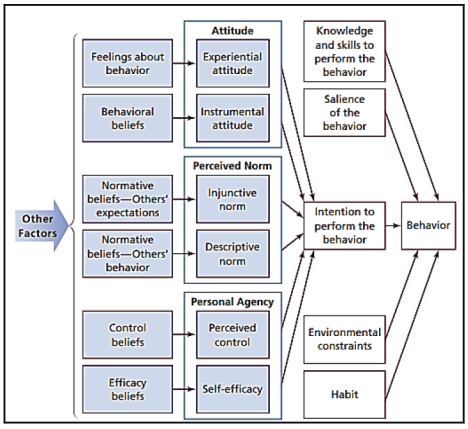


Figure 2. Self-Explanatory Intention Action/behaviour co-integrated model[4].

Theory of planned behaviour, founded on the notion that perceived consumer efficacy, perceived awareness, and environmental attitude contribute to green purchasing intention[5]. Most people now understand that being green is an important business problem, not just a trend in marketing[6]. What's more, male, young, highly educated, and high-income consumers have higher Consumer innovativeness; male, elderly, less-educated, and low-income customers have a bigger effect on Green Consumption behaviour[7]. Due to green consumerism and rising concern's over environment health a radical shift in construction material has caused many innovative smart materials like contemporary brick materials such as mud, wool, and even cigarette's burnt end and its ash may be used to manufacture bricks that will be just as strong without the need of furnace fires, which emit hazardous pollutants[8]. Nature-inspired design produces energy-efficient products in the setting of a climate emergency, thermally comfortable structures that are both buildable and sustainable[9]. As per research agency Deloitte which shows us intention of consumers in adopting sustainable consumption.

It is clear that preparation for changing to a more sustainable lifestyle plays a crucial role at both the organisational and personal levels[10]. The findings of the experiments suggest that conductive geopolymer might be deployed as a smart material in concrete structural wellbeing and health monitoring applications[11].

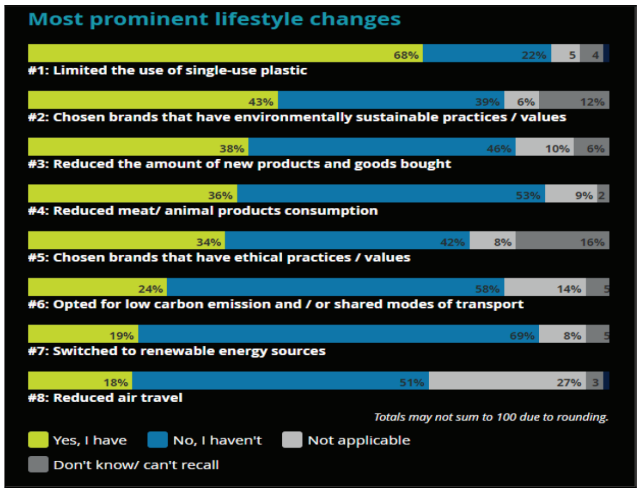


Figure 3. Consumer survey by Deloitte[1] on shifting perspectives towards sustainable consumption as their goals.

[b] Shifting sands: How consumer behaviour is embracing sustainability – Deloitte.

2.0 Literature Review

2.1 Different Smart, Sustainable and Green Materials and its Impact on Environmental Health

2.1.1 Smart Concrete

2.1.1.1 Self-healing Smart Concrete

Bio concrete a microbial self-healing technique is characterised by its ability to heal cracks in a fast, and active manner while being ecologically caring. Bio-mineralization refers to the process of mineral formation by living organisms[12]. Biologically induced mineralization often happens in an open environment as an unregulated result of microbial cell metabolism activity[13].

Bio-minerals are synthesized in this mechanism by the interaction of metabolic products produced by microbes with the surrounding environment, resulting in the formation of calcium carbonate ($CaCo_3$), Mineral precipitation happens as a result of the effective adhesion of positively charged ions to negatively charged microbial cell walls, which heals the fissures/cracks on its own[15]. This a green and sustainably smart material of this era.

Thus, smart concrete reduces consumers repair charges and making them save repair cost in longer run due to low maintenance and enhanced building longevity.

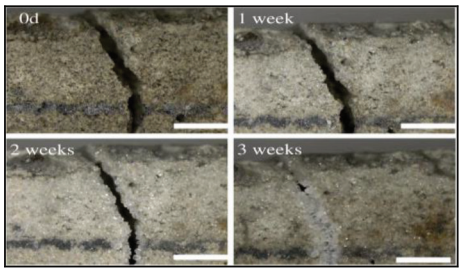


Figure 4. An illustration of a fissure recovery process (from the NCS5 per cent in 'wd + water' series)[14].

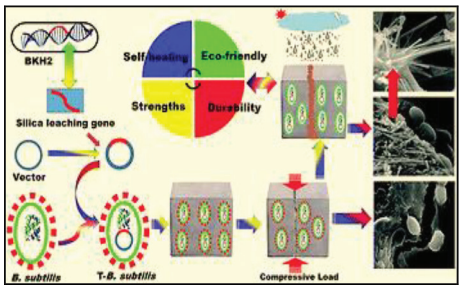


Figure 5. Beneficial features of self-healing bio-concrete[16].

2.1.1.2 Recycled Plastic in Concrete

Only a few years ago, the concept of employing recycled resources in concrete manufacturing was largely unknown[17]. This concrete reduces greenhouse gas emission and new life to polythene waste[18]. In recent times 10% of sand is replaced with recycled plastic[19], this reduces usage of sand in the structure thus saving natural habitat of river and water sources, which otherwise would have been destroyed due to over excavation of sand for construction due its scarcity.

2.1.1.3 Precast Concrete

These slabs use far less energy to make than traditional concrete slabs, and this material has exceptional strength due to its wide hollow spaces with less porosity on surface and denser, which hold up well to all weather conditions and are less prone to cracks and even earth quakes of higher magnitude[20], chiefly this precast concrete reduces job site pollution as less construction materials are used[21]. Typically used for flooring, walls, and ceilings, high rise building and even building bridges.

2.1.2 Carbon Reducing Material

2.1.2.1 Hempcrete

It is a natural material made of fibres combined with lime to make robust and light concrete-like formations.

It is strong and lightweight than traditional bricks, has superior thermal and sound insulation, and is flame resistant[23]. Furthermore, its most important sustainable attribute is that it captures more CO_2 than it emits. Lack of certification and recognition from government in India leads to lack of knowledge about such an innovative smart and green material[9].

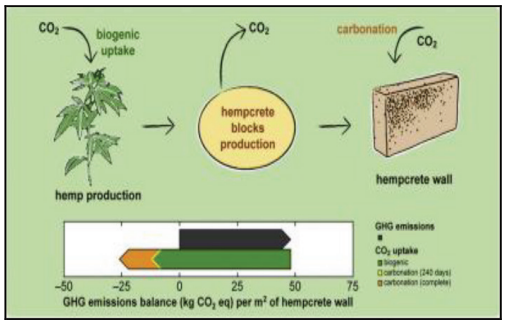


Figure 6. Hempcrete production process and how it reduces CO_2 in its usage[22].

2.1.3 Shape Memory Smart Materials

2.1.3.1 Cork

This is formed of tree bark and other renewable materials it is highly flexible, tough, and light in weight, with the remarkable property of returning to its original shape after sustained pressure (shape memory), making it easier to move and using less fuel for transportation logistics, majorly used in flooring[24].

2.1.3.2 Nickel and Titanium Based

Among the many Shape Memory Alloys (SMA), Nickel-Titanium has so far demonstrated outstanding shape memory effect behaviour, with large magnitudes of shape recovery, recovery stress, and pseudoelastic strain[25].

2.1.4 Sensing Material (Sensing Materials)

2.1.4.1 Piezoelectric

Conventional polymer-based piezoelectric composites are employed in civil constructions due to their unique and asymmetric rate of expansion[26]. A new system called "WiAMS" a wireless sensor mounted with smart piezoelectric transducers used to detect and evaluate the damage severity level in flexural and shear-critical Reinforced concrete element[27].

2.1.4.2 Magnetostrictive Materials

One of the more seasoned "newcomers" that is rapidly entering the market is Magnetostrictive (MS) technology[29]. Magnetostrictive materials, which can transform magnetic energy into kinetic energy or vice versa, and are employed in the civil structural constructions like actuators and sensors implanted inside pillars

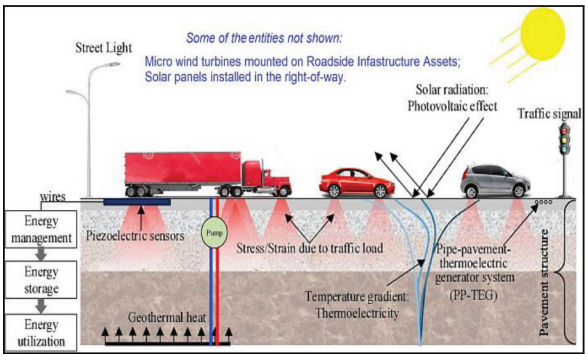


Figure 7. A method of energy harvesting implemented in road construction that transforms mechanical energy into electrical energy that uses piezoelectric sensors[28].

or beams (Wikipedia, 2022). Giant Magnetostrictive Materials (GMM) and piezoelectric materials have been in rivalry since the creation of Terfenol-D[30]. Due to the fact that the displacement per unit magnetic field grows with dimension, magnetostriction favours big, powerful actuators that can handle the demands of massive civil constructions.

2.1.5 Smart and Green Coating Materials

2.1.5.1 Aerogels

It is a unique solid element with nanometre-scale pores. Porosity is greater than 90%, occasionally reaching 99.9%, and densities are in the range of 3 kg/m^3 [31]. In recent years, further advancements in aerogel have been made by combining aerogel with metal-organic frameworks at the molecular level to create advanced composites that are expected to improve their performance in trapping pollutants from the environment, including water and air, thereby helping to improve the quality of the environment and make it more sustainable[32].

2.1.5.2 Graphene

Antimicrobial surface coatings based out of graphene decreases the spread of transmittable microorganisms, specifically SARS-CoV-2 and bacteria. Because of specific super-hydrophobic qualities in the case of Graphene Based Nanomaterials, the anti-biofouling mechanism repels bacteria and prevents them from sticking to the surface[33].

It is evidently seen through this literature review that smart and sustainably greener material enhances the environmental health and magnifies the quality of consumer's life by reducing hazardous effects on environment. In a nutshell, smart, green and sustainable construction materials facilitate better environmental health and offer better scope for green consumerism.

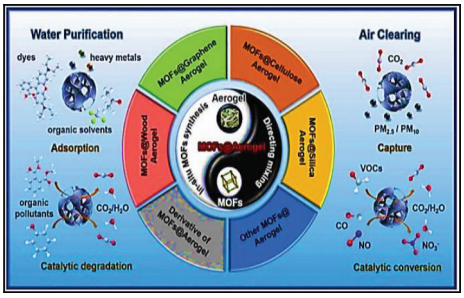


Figure 8. Pictorial representation of MOF's with aerogel in action in trapping air and water pollutants[32].

2.2 Challenges Encountered while Implementing Smart Materials in Construction and Solutions

Smart material in construction sector looks very promising in terms of its benefits to consumers and environment health. But, there are multi-layered challenges that surface up during deployment of smart material in construction, they are:

2.2.1 Consumer's Awareness

There is a lack of consumer awareness on smart material, typically due to poor promotional and marketing efforts by manufacturers. Also, consistent Environment health related education and smart materials contribution to enhanced environment wellbeing may induce consumer to buy it as it stimulates environmental awareness in consumers.

2.2.2 Sub Conscious Conditioning

Due to various latent/hidden motives consumers will be reluctant in intending to purchase smart material as anxiety about approval of family, peers and reference group may impact purchase intent of smart material in consumers. This problem may be solved by influencing target audiences by using leading film actors or famous personalities who have power to influence the unconscious minds of consumers in shifting their perspective to sustainable options and this is achieved by repetitive advertisement in a fixed frequency. After some time of classical conditioning automatically sets in without even visually seeing the advertisement. The consumers will be able to remember the smart material whenever other advertisement related to environment protection is displayed these phenomena is also referred to subconscious marketing (cross reference) the reduction in reluctance level will be noticeable after this effect.

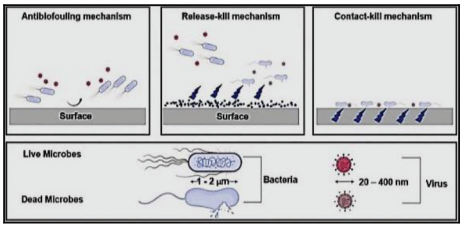


Figure 9. Three major antibacterial material mechanisms on diverse surfaces[33].

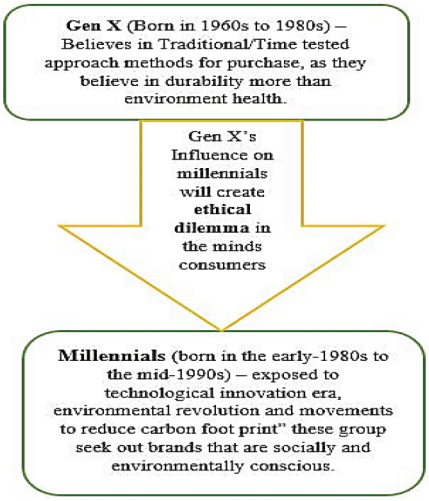


Figure 10. Ethical dilemma - Generations X's influence on millennial consumption of smart, sustainable and green materials.
Source: own

2.2.3 Ethical Dilemma

Consumers are reluctant to use smart materials due their previous generation's influence on millennial. Figure 9 describes how ethical dilemma occurs as an effect of previous generation influence on millennials and how to eliminate ethical predicament.

Thus, through this literature survey we are able to map out that multifaceted challenges in deploying smart material in construction withholds the potential utility of the smart materials in terms of effective usage and adoption, which is reason behind intention-action gap of the consumers.

3.0 Research Methodology

A descriptive study was undertaken on the smart and green construction materials, its impact on environment health in the context of evolving consumer awareness. The judgement sampling technique-based survey has been conducted among the consumers and contractors/ builders of construction sector in Karnataka region, to identify the patterns of smart and green material's consumption in construction sector from 384 and 34 respondents was gathered and used for the study. Different statistical analysis, including the Chi-square test, Analysis of Variance (ANOVA), multiple regression, and binary logistic regression, were used to analyse the data. The results are expected to confirm the influence



Figure 11. Portrays challenging factors affecting the smart material purchase decision which acts as psychological and physiological drivers in terms of smart material adoption.
Source: own

of smart construction materials on green consumerism using a data-based approach.

4.0 Data Analysis and Interpretation

Data analysis is the purposeful application of systematic procedures to represent and portray, summarize and analyse information.

Majority of the respondents are employed in private sector. The private employees have a higher mean score (4.21) for global warming knowledge than other employment type. The p-value of One-way ANOVA is significant indication the rejection of null hypothesis. Thus, there is a significant difference in awareness level of global warming among the different categories of employment of the respondents. Further, to explore which type of employment are significantly differing from other employment type with respect to awareness level of the global warming, Post hoc analysis is employed. Post hoc test decisions are subject to the homogeneity in variance. Thus, Levene's test has been conducted to verify whether the variances are homogeneous or not. The results of Levene's test and Post hoc are shown in Tables 2 and 3.

The significance of Levene's statistic implies that there is no homogeneity in variance and Games-Howell test is used in the post hoc analysis to find the extent of differences.

The Table 3 shows that Private organization employees' awareness level on global warming is significantly higher than other employment type.

The p-value is less than 5%, implying that the there is a significant positive connection between the variables. The respondents' having higher level of awareness of smart construction material also have higher level of agreement

Table 1. Awareness level vs. employment

H_0: There is no significant difference between awareness level on global warming and type of employment.		
Employment Type	**N**	**Mean score**
Self-employed	60	3.88
Private	255	4.21
Government	23	3.39
Other	46	3.48
Total	**384**	**4.02**
One-way ANOVA		
F-statistic	9.429	
P-value	0.000***	

*** significance at 0.01

Table 2. Levene's test for homogeneity

H_0: Homogeneity is assumed			
Levene Statistic	**df1**	**df2**	**P-value**
41.647	3	370	0.000***

*** significance at 0.01

Table 3. Post hoc Test for ANOVA

Emp. (i)	Emp. (j)	MD (i-j)	P-value
SE	Private	-0.325	0.204
	Govt.	0.492	0.489
	Other	0.405	0.551
Private	SE	0.325	0.204
	Govt.	0.817	0.066
	Other	0.730*	0.043**
Govt.	SE	-0.492	0.489
	Private	-0.817	0.066
	Other	-0.087	0.996
Other	SE	-0.405	0.551
	Private	-0.730*	0.043**
	Govt.	0.087	0.996

** significance at 0.05

that smart material increases the environment health and vice-versa in Table 4.

Table 5 illustrates that all of the exogenous variables have a significant bearing on the dependent variable. Among the independent variables, social factors are more prominent in explaining the variation in use of smart and sustainable materials in construction as its co-efficient

Table 4. Correlation

H_0: There is no significant relationship between variables			
		a	**b**
a	Pearson correlation	1	0.162
	p-value		0.002***
b	Pearson correlation	0.162	
	p-value	0.002***	

*** significance at 0.01

Note: a = Level of awareness of smart and sustainable construction material; b = Level of agreement that smart and sustainable material increases environmental health.

Table 5. Multiple regression

H_0: Dependent variable is not significantly influenced by the independent variables.			
ANOVA			
Model	**Mean square**	**F**	**p-value**
Regression	268.76	67.19	0.000***
Co-efficient			
Variable	**β**	**t**	**p-value**
a	0.410	9.89	0.000***
b	0.232	4.55	0.000***
c	0.228	4.47	0.000***
d	0.192	3.89	0.000***

*** significance at 0.01; Adj. R2 = 0.655

Note: Dependent variable = Willingness to use smart and sustainable materials in construction; Independent Variables: a = Social factors; b = Economic related factors; c Environment related factors; d = Climate change and Environmental problems.

is higher than others. With an adjusted R^2 of 0.655, all independent variables collectively can explain 65.5% dissimilarity/variance in the use of smart materials in construction.

From Figure 10 we can understand that mean score for poor product education is higher than all other variables. This specifies that the most important constraint in using the smart materials is due to poor product knowledge. Thus, proper awareness and education on the use of smart and sustainable materials are necessary to enhance the usage of smart and sustainable construction materials.

From Table 6, we see that the significant p-value of Chi-square test represents that the independent variables – Income, Residence and Environment are together significantly predicting the usage of smart and sustainable

material in construction. Nagelkere R square value indicate that 29 per cent change in use of smart and sustainable material in construction is significantly predicted by the independent variables. Income has a significance value of 0.018, indicating that respondents' income shapes their use of smart and sustainable construction materials. Environment consciousness is the most prominent variable that effects the use of smart and ecological construction materials as it is significant and explains 73.8 per cent change in the use of smart and sustainable materials in construction.

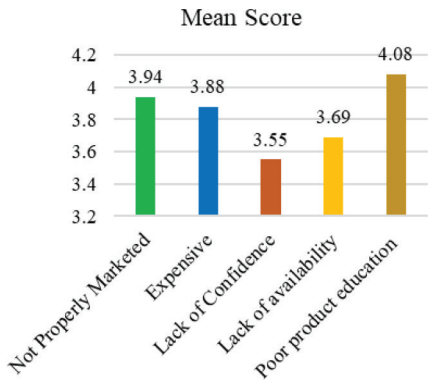


Figure 12. Challenges in using smart and sustainable materials.

The second aspect of the study focuses on builders and contractors to better understand the barriers to employing innovative, sustainable, and green building materials. The study involved 34 contractors and builders. The four main challenges to use smart, green, and sustainable materials are: insufficient market demand for

Table 6. Binary logistic regression

H_0: Independent variables are not significant in predicting Dependent variable			
Chi-square		**p-value**	
71.19		0.000***	
Model Summary			
Nagelkerke R Square		0.29	
Variables in the Equation			
	Variables	**β**	**p-value**
Step 1[a]	**Income**	0.072	0.018**
	Residence	0.210	0.138
	Environment	0.738	0.000***

*** significance at 0.01; ** significance at 0.05

a. Variable(s) entered on step 1: Income, Residence, environment. Dependent variable = use of smart and sustainable material

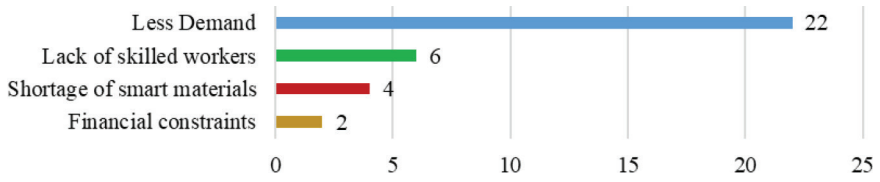


Figure 13. Constraints to use smart, green and sustainable construction materials

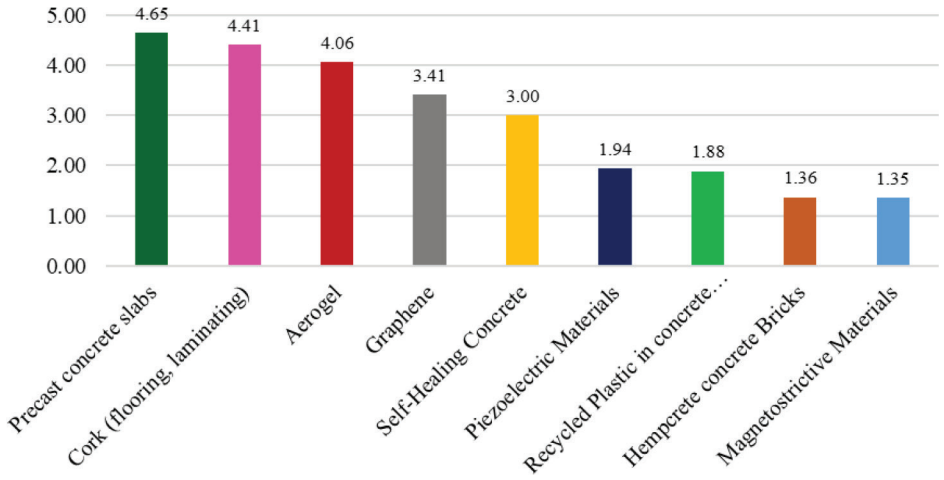


Figure 14. Smart materials with frequent use (Mean score)

Table 7. Two-way ANOVA

H_0: There is no significant difference in the 'frequency of suggestions to use smart materials' across the different categories of 'Number of green projects developed' and 'reasons for motivation to suggest smart material'.		
Dependent variable: Frequency of suggestions given by builders to use smart construction material		
Predictors	**F-stat.**	**P-value**
Green projects developed	0.703	0.559
Reasons for motivation to suggest smart materials	21.154	0.000***

*** Significance at 0.01 level

these products, primarily due to lack of knowledge about their benefits; inadequately trained workers who are proficient at employing smart and sustainable building materials, shortage of smart materials and equipment owing to supply side constraints, and financial limitations to use smart and sustainable construction materials due to their higher cost.

22 respondents felt insufficient market demand is the most important constraint for the smart and sustainable building materials. Only 2 respondents felt financial constraint is the reason for the minimal usage of smart construction materials.

Numerous smart materials like precast concrete slabs, Cork (flooring, laminating), Aerogel, Graphene, Self-healing concrete, piezoelectric materials, recycled plastics in concrete mix, Hempcrete concrete bricks, Magnetostrictive materials etc., are used in the construction sector. Figure displays that the mean score of precast concrete slabs is 4.65 and it is most commonly used smart materials in construction projects. This is followed by Cork (4.41) and Aerogel (4.06). Magnetostrictive Materials and Hempcrete concrete bricks are found to be the least used smart materials in the construction with mean score of 1.35 and 1.36, respectively. Figure 12 shows the list of smart materials with frequent use in construction sector.

The two-way ANOVA statistical technique is employed to examine whether or not the 'frequency of suggestions given by builders to use smart construction materials' is varying across the different categories of 'green projects developed by the builders' and the 'reasons for motivation to suggest smart material'.

In Table 7, the p-value of 'Green projects developed' is 0.559 indicating the acceptance of null hypothesis. This represent that there is no significant difference in the responses on 'frequency of suggestions to use smart materials' across the categories of 'green projects developed'. The p-value of 'Reasons for motivation to suggest smart materials' is 0.000 signifying the rejection of null hypothesis. Thus, there is a significant difference in the responses on 'frequency of suggestions to use smart materials' across the categories of 'reasons for motivation to suggest smart materials. This implies that the different categories of 'reasons for motivation to suggest the use of smart materials' have a varying impact on 'frequency of suggestions to use smart materials.

5.0 Conclusion

This research unravelled many of the challenges plaguing smart construction material. The challenges were; poor education about the benefits of smart construction material towards environmental health. This was found to be a major factor for reluctance in adoption of smart construction material. Poor marketing, high cost of smart material, insufficient availability were other prominent variables that affect the respondent's adversely towards usage of smart material. On the other hand, environmental consciousness acted as a prominent agent in embracing of smart construction material, as it led the consumers to behave responsibly towards their immediate environmental welfare. Further, consumer survey indicates us that willingness to use smart and sustainable construction material was dependent on social, economic, environment and climate change. A separate segmenting strategy can be focused more on private sector employees as they showed high awareness towards different smart materials. In the builder survey, in this study noteworthy factor's that adversely affected the deployment of smart, sustainable and green material in construction sector, the adverse effect was due to the insufficient demand, and lack of skilled workers in using smart material in construction sector. It is noted that more precast concrete slabs, self-healing concrete, crock, aerogel, piezoelectric, and graphene were highly used material, we found less used were, recycled plastic and hempcrete bricks. The analysis, we conclude that there are multifaceted strong influential factors that exert positive and negative impact on consumers in adoption of smart construction material under the domain of green consumerism. Henceforth, smart material marketers should streamline their efforts

in segmenting by product type and application and targeting the environmentally conscious consumers, private sector employees and urban consumers by emphasising more on classic condition psychological approach to engender habituation of smart material. Also Binding high-cost aspect of smart material with the noble reason like some portion of sales proceeds going towards reducing carbon footprint globally gives a sense of enhanced morality and consumer will become loyal in long-run. Nevertheless, for rural and low-income segment more of educative advertisements has to be implemented and smart material cost optimisation is required. Finally, environmental conscious element has to be imparted in minds of consumers to make them realign/shift from traditional to greener and more sustainable consumerism. Due to the increased need for sensors and actuators in the construction industry, the market for smart materials is expected to experience significant expansion in the future. Additionally, the construction sector is moving away from traditional building materials and toward sustainable and green alternatives. The market for smart materials has significant potential, and future R&D expenditures by leading industry participants will present significant development prospects.

6.0 References

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