Final Report

for the project

Green Residential Housing - Making Cost Effective & Affordable

Submitted to

National Housing Bank

INDIAN INSTITUTE OF MANAGEMENT SIRMAUR

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Executive Summary

India, like most of the large developing economies, is witnessing increased urbanization due to better infrastructure and livelihood opportunities available in the cities. This trend, coupled with increasing population, is leading to stress on the existing urban infrastructure and has created a need for more building space. The increase in the urban population is leading to a shortage of urban housing. Addressing this urban housing shortage, therefore, calls for a dramatic increase in the building space in the cities. The need for sustainable cities is also driven by the global megatrend of increased urbanization.

Taking cognizance of the urban housing shortage, the Ministry of Housing and Urban Affairs, Government of India launched the Pradhan Mantri Awas Yojana – Urban (PMAY-U) project to provide houses to all urban households. This plan takes into consideration the imperatives of affordability and sustainability by developing affordable green housing. This scheme also contributes to United Nations' sustainable development goals (SDGs).

Multiple government agencies and institutions in India are contributing to the efforts of the Ministry of Housing and Urban Affairs in promoting green and affordable urban housing. One such agency is National Housing Bank (NHB). The current research project advances NHB's vision by addressing the question *'how can green housing be made affordable'*? As cost of green construction material is one of the key reasons for cost premium associated with green housing, this study focuses on the following three research objectives (ROs) related to green materials.

(i) RO1: To trace the supply chain of green construction materials in India to understand the challenges encountered by supply chain members.

(ii) RO2: To identify the factors leading to higher cost of green construction materials.

(iii) RO3: To develop a hierarchical model among the cost factors for green construction material and understand the interrelationships among them.

In line with the nature of ROs, a multi-method approach to collect data was used. To meet the first and second ROs semi-structured interviews were conducted with members of green material supply chain in India. To reach diverse respondents, the research team approached their contacts and also employed a snowball approached. A total of thirty-five interviews were conducted. The respondents were associated with different stages of the green materials supply chain and were associated with firms dealing with green paints, green cement, environment friendly bricks or blocks, and glass. The text data obtained through interviews were analyzed using thematic analysis to address ROs 1 and 2. Total Interpretive Structural Modelling (TISM) was used to understand the interrelationships among the cost factors (RO3) identified through thematic analysis. For this, a survey was conducted among experts and synthesizing their inputs, a hierarchical model was developed to visually represent relationships among the cost factors.

Five specific themes and twelve sub-themes on challenges relating to external environment, operations, inbound and outbound logistics, and marketing and sales were identified. These reveal that supply chain members are encountering challenges relating to external environment due to difficulties in procuring fly ash (to make fly ash bricks), gaining to access to segregated municipal waste (for producing paver blocks or tiles), and scrap steel (to make green steel). These problems were further aggravated by a lack of awareness among end-users regarding specific environmental and economic benefits of green materials. The lack of awareness is found to be a recurring issue across interviews, cutting across respondents from firms dealing with different green materials. This challenge has been found to further manifest in the form of or indirectly lead to other challenges like limiting the demand and overall market size of green materials, resistance from ‘influencers’ like architects and contractors to switch to green materials, lesser number of suppliers for raw materials and production machinery (and trained technicians therein), and uncertain demand for finished products (green materials) leading to higher inventory.

To address RO2, four categories of cost and nine specific cost factors were identified. These categories pertained to fuel and energy, logistics, marketing and production, and raw materials. It was also found that the identified challenges in green material supply chain were directly or indirectly influencing the cost factors and leading to higher cost of green materials. For instance, the challenge pertaining to lack of end-user awareness and lower demand called for higher expenses in marketing and advertising activities and also contributed to higher inventory costs. Similarly, challenges pertaining to the availability of raw materials manifest in terms of costlier raw materials and consistent rise in raw material cost over the years. Owing to significant rise in fly ash cost, the latter was found to be a bigger problem in case of environment friendly bricks or blocks that incorporate fly ash as a key constituent. Another challenge contributing to increased cost of raw material was found to be rising fuel prices that directly impact transportation and production cost. These complex interrelationships among the nine cost factors were captured in a hierarchical model developed using TISM.

The study concludes with recommendations to address the identified supply chain challenges and cost factors. Since lack of end-user awareness appears to be the overarching problem, it must be addressed on priority. To this end, government agencies (at central, state, and municipal levels) and various industry associations should take more initiatives to increase awareness regarding the environmental and economic benefits of green housing and green construction materials. Such efforts should specifically target the small-scale firms operating as contractors and architects, who could, in turn, educate individual and corporate end-users regarding green housing and green materials, and encourage them to perceive the premium associated with first cost of green buildings as an 'investment' that would be returned in terms of financial benefits (lower electricity and water expenses, for instance) and better health (for instance, through non-toxic, low VOC paints and better indoor air quality). Moreover, to increase the end-users' 'willingness to pay' more and more green material manufacturers should be made aware of the process for and encouraged to obtain certifications for their products. With regards to addressing the issue of costlier raw materials, the producers of fly ash (i.e. power plants) need to be sensitized of the problems being faced by the small-scale producers of fly ash bricks. The tendering-and fixed quota-based system for supply of fly ash may be re-looked into. Similarly, in the case of paver blocks the cost of raw material can be reduced by extending more assistance through municipal corporations in supplying segregated plastic waste to the manufacturers. Finally, to address the factors pertaining to fuel and energy, switching over to renewable energy would be a clear and preferable option as the same would bring down the production cost. An opportunity exists here for industry associations and government agencies to facilitate transition of small-scale green material manufacturers towards renewable sources. Such transition will not only bring down the product cost but also ensure that these materials become even 'greener' through further reduction in their carbon footprint.

1. Introduction

In line with the trends in most of the large emerging economies, India is also witnessing increased urbanization due to better infrastructure and livelihood opportunities available in the cities. This trend, coupled with increasing population in India, is leading to stress on the existing urban infrastructure and has created a need for more building space. As per report of the Technical Group on Population Projections, National Commission on Population, India's total population and the share of urban population stood at 121.1 crore and 31.8 per cent respectively in 2011 and these were projected to increase to 151.8 crore and 38.6 per cent respectively by 2036 (National Commission on Population, 2019). The report also estimates that almost 73% of this increase in the Indian population is going to be in the urban areas. Increase in the urban population is already leading to a shortage of urban housing. A recent study by Indian Council for Research on International Economic Relations examined the urban housing shortage in India from the perspective of physical inadequacy of housing. Findings of this study suggest that the urban housing shortage in India has increased by 54% between 2012 and 2018; from 18.78 million units in 2012 to 29 million in 2018 (Indian Council for Research on International Economic Relations, 2020). Addressing this urban housing shortage, therefore, calls for a dramatic increase in the building space in the cities.

However, the construction of new building space in urban areas needs to be done in a mindful manner otherwise it could further add to India's burgeoning greenhouse gas (GHG) emissions and make achievement of India's commitment to become carbon neutral by 2070 more difficult. It is so because construction and operation of buildings has been identified as one of the major sources of GHG emissions worldwide (UNEP, 2022). Therefore, the construction of new buildings in the urban areas needs to be done in an environmentally conscious manner.

Another notable characteristic of the urban housing shortage in India is its concentration in the low income groups among the urban population, which account for around 96% of the total housing shortage (Indian Council for Research on International Economic Relations, 2020). Hence, apart from being green or environmentally sustainable, the new building stock developed to bridge the urban housing shortage must also be affordable for its intended beneficiaries.

Taking cognizance of the quantum and nature of urban housing shortage in India, the Ministry of Housing and Urban Affairs, Government of India, launched the Pradhan Mantri Awas Yojana – Urban (PMAY-U) project to provide houses to all urban households. This plan takes into consideration the imperatives of affordability and sustainability of buildings by undertaking development of affordable green buildings. In this manner, this scheme also seeks to directly contribute to multiple sustainable development goals (SDGs) formulated by the United Nations. Construction and operation of affordable and sustainable housing provides a clean, hygienic, and respectable place of living to people from economically weaker sections, enables cities to grow in an environmentally conscious manner, strives to reduce inequality between the urban communities, and signifies a more responsible approach for the construction industry. In this way, promotion of green and affordable housing directly and indirectly contributes to SDGs 3, 6, 10, 11, 12 and 13 (Figure 1).

Figure 1 The Sustainable Development Goals
Source: United Nations, Department of Economic and Social Affairs

Multiple government agencies and institutions in India are contributing to the efforts of the Ministry of Housing and Urban Affairs in promoting green and affordable urban housing. One such notable agency is National Housing Bank (NHB). NHB is serving society with a vision of "promoting inclusive expansion with stability in the housing finance market." The current research project and this report advance NHB's vision by investigating ways of making green housing affordable.

The rest of this report is organized as follows. Section 2 presents a brief review of literature on the need for developing green housing and the barriers encountered in this regard, and identifies a specific gap with respect to green construction materials towards making green housing affordable. Section 3 presents the three objectives of this study and section 4 describes the methods adopted to collect and analyze data for addressing the objectives. Section 5 presents the details of data collected and findings. Section 6 concludes the report with recommendations to address the challenges and cost factors to make green construction (and consequently green housing) mode affordable.

2. Literature Review

The construction industry significantly contributes to environmental degradation resulting in rapidly declining natural resources and greenhouse gas emissions. Buildings exert a substantial and rapidly growing influence on the environment. Globally, buildings are responsible for approximately 40% of energy usage and 30% of energy-related GHG emission (UNEP, n.d.). According to the International Energy Agency (IEA), in 2022 the energy consumption in the buildings sector saw a slight increase of approximately 1% compared to the previous year (IEA, 2023). In addition, a poor quality of indoor environment in office buildings can lead to serious health issues among employees, consequently reducing productivity (Ries et al., 2006).

To address deteriorating environmental conditions, the concept of green housing has garnered traction as a sustainable approach to minimize the adverse impact of construction activities and constructed buildings. The extant literature suggests that higher cost of green housing (as compared to traditional buildings) is one of the most significant barriers for the development and adoption of green housing, especially in the developing economies (Darko et al., 2016; Hohl &

Lotfata, 2022). As stated by Pandey (2023) and Saha et al. (2021), high cost associated with green housing is a major barrier to its adoption in India. Empirical evidence from recent research affirms the cost premium of green housing in the Indian context (Saha et al., 2021; Samari, et al., 2013). According to Vyas and Jha (2018), the average increment in the initial cost of a three-star green housing in India is 3.10% and that for a five-star green housing is as high as 9.37%. Pandey (2023) posited that the cost of green housing compared to that of traditional buildings can be around 5% higher in tier I cities and even greater in tier II and tier III cities. Such expenses demotivate the customer from investing for the environment.

A crucial aspect of green housing is the selection of green constriction materials. Yet, a widespread use of green materials is inhibited due to the perception that these materials are costlier as compared to conventional materials. Most of the materials used in developing green housing, such as bricks or blocks, insulating material, flooring tiles, paints, and adhesives and roofing materials are generally expensive as compared to conventional materials (Wang et al., 2018). For instance, Joyram (2019) estimated that the cost of each eco-block is almost double that of a conventionally used block. Many other empirical studies from India as well as other developing economies have also established higher cost of green construction materials vis-a-vis conventional construction materials (Hwang and Ng, 2013; Sudarsan & Sridharan, 2021).

The higher cost can be attributed to costlier design, difficulty in procuring and high cost of building material for green housing. Many green housing materials often require specialized sourcing and production methods. The limited availability of these materials can result in higher costs due to increased transportation expenses and processing requirements (Wang et al., 2022). The scarcity and procurement challenges drive up the cost of green building materials (Jiang and Payne, 2022). After procuring, the installation of green building materials can prove to be costly. The installation of certain green materials may require skilled labor with expertise in handling these unique materials. The scarcity of skilled workers can drive up labor costs, and the intricate installation processes can lead to longer construction timelines, adding to overall project expenses (Zhang et al., 2011; Hohl & Lotfata, 2022).

However, despite being commonly identified as one of the prominent barriers to green housing, there is a lack of studies in the Indian context that have (i) investigated the supply chains of green construction materials to gather the challenges encountered by the supply chain members, and (ii) explored ways in which these materials could be made cheaper, thereby reducing the initial cost premium associated with green buildings and making green buildings affordable. The current study seeks to address these gaps through field studies that trace the supply chain of green materials to understand the challenges and cost factors that contribute to higher cost of green construction materials. Based on the findings, this report makes recommendations towards making green housing affordable by addressing the identified cost factors.

3. Research Objectives

In line with the background presented in the previous sections and the research gaps identified therein, the following three research objectives (ROs) were finalized:

RO1: To trace the supply chain of green construction materials in India to understand the challenges encountered by supply chain members.

RO2: To identify the factors leading to higher cost of green construction materials.

RO3: To develop a hierarchical model among the cost factors for green construction material and understand the interrelationships among them.

4. Research method

In line with the aforesaid objectives of this research, this study uses a multi-method approach in which different research methods are employed to collect data. To meet the first and second RO2 a field survey was conducted. This survey involved reaching out to different members of the green construction material supply chain to gain a better understanding of the overall supply chain and gather information on challenges being encountered by these members with respect to the activities performed by them in the value chain. During these surveys the data was collected through semi-structured interviews with supply chain members. In view of a lack of existing primary data on challenges and cost factors associated with the supply chain of green construction materials in India, semi-structured interview was considered to be the most suitable method for data collection for this project (Qu and Dumay, 2011).

The interview protocol included a few set questions supplemented with additional questions based on the response from each respondent. Each interview started with descriptive questions to collect details of the firm size, the material, firm's role in green construction material supply chain, role and designation of the respondent. This was followed by open-ended questions pertaining to the cost of the material, challenges encountered by the firm while portraying its role in the supply chain, factors contributing to making green materials costlier, and possible interventions for bringing down the cost. These questions were interspersed with specifying questions and direct questions, and follow-up questions and probing questions as required.

To reach a diverse set of respondents connected to different activities of value chain and relating to different green construction materials the research team employed a snowball approach. The initial set of respondents was identified by the research team members utilizing their own contacts. Each potential respondent was approached with a request to participate in the interview and given assurance of complete anonymity of their firms and responses. Interviews were conducted in both physical mode as well as telephonically. Those who agreed to participate were interviewed and at the end of interview they were requested to guide the research team to other potential respondents from firms essaying a similar or different role in the supply chain. Interviews were voice recorded with prior permission of the respondent. This process was continued and the obtained responses were transcribed and analyzed. Interviews were continued till data saturation was observed.

The text data obtained through the interviews was analyzed using thematic analysis in order to identify specific themes pertaining to challenges and cost factors (and thereby address ROs 1 and 2 respectively). Thematic analysis is a method that uncovers, analyzes, and presents patterns (themes) within data, providing a detailed and comprehensive understanding of the dataset (Braun & Clarke, 2006). The analysis was conducted in the following five sequential steps:

(i) Familiarization with the data: Becoming well-acquainted with the dataset involved a thorough reading and revisiting the entire data to gain a deep understanding. This process was essential for recognizing pertinent information that aligns with the research questions.

(ii) Initial codes generation: Codes represent the foundational elements from which themes emerged. The coding process involved creating concise and abbreviated interpretive labels for pieces of information that could hold significance in relation to the research objectives. Categorization of codes enabled identification and development of overarching themes that ultimately helped address ROs 1 and 2.

(iii) Theme generation: This stage commenced once all pertinent data items had undergone coding. During this step, the emphasis transitioned from interpreting individual data elements within the dataset to comprehending the aggregated significance and meaningful patterns across the entire dataset. The coded data was meticulously examined and analyzed to explore how various codes could be amalgamated based on shared meanings, leading to the formation of themes and sub-themes. This process involved consolidating multiple codes that encapsulate a similar underlying concept of the data into a single, more encompassing theme.

(iv) Review of potential themes: In this phase, a recursive review of the potential themes, considering their relationship to the coded data items and the entirety of the dataset was conducted. This involved a thorough and iterative examination of how the identified themes aligned with the coded information at both the individual data item level and the broader dataset level. The aim was to ensure coherence and consistency in the thematic analysis, refining and validating the identified themes through a comprehensive and reflective assessment of their alignment with the underlying coded data.

(v) Finalizing the themes: The process of finalizing the themes necessitated a thorough analysis of the underlying data items. This involved delving deeply into the intricacies of the data, identifying patterns, connections, and shared meanings among the coded elements. During this phase, a comprehensive analysis of the thematic framework was conducted. Each individual theme and sub-theme was articulated in connection to both the dataset and the research questions. Adhering to Patton's (1990) dual criteria, every theme is expected to offer a coherent consistent narrative of the data that brings forth unique insights not conveyed by the other themes. Simultaneously, all themes converged to construct a clear and cohesive narrative aligned with the dataset's content and provided valuable information in relation to the research objectives.

The cost factors identified through the thematic analysis of the interviews were used to address the third objective (RO3) of this study. For this purpose, Total Interpretive Structural Modelling (TISM) was used. TISM is a comprehensive statistical and analytical approach used to examine complex relationships and interactions among various factors or variables in a system (Deepu & Ravi, 2023). It is particularly useful for exploring and modeling complex systems, such as organizational structures, supply chains, or other interconnected phenomena, to gain insights into their underlying structures and dynamics (Sindhwani et al., 2022).

Before conducting TISM analysis, a survey was conducted with experts to obtain their view on the relationships among the nine cost factors. Synthesizing their inputs, a hierarchical model was developed that provides causal relationships among the cost factors. The following steps were followed for applying TISM:

(i) Identification of the cost factors: The first step involved identification of the cost factors that led to high prices of green materials. These factors were already in place through the thematic analysis of interview data of supply chain members.

(ii) Comparing the cost factors: A survey was conducted to understand the relationships among the identified cost factors. In the survey, experts were requested to relate each cost factor with every other cost factor in the form of a pair-wise comparison. In each comparison, experts used "Y" to indicate a relationship ("Yes") or "N" to signify no perceived relationship. Different experts may have different responses and hence the 'mode' of responses was used to aggregate different opinions in the reachability matrix (Khatwani et al., 2015)

(iii) Reachability Matrix: In this matrix, a binary value of 1 or 0 was assigned in the i-j cell; where i represented the row and j represented the column, indicating "Yes" or "No" respectively. This binary representation reflected the presence or absence of a relationship between the factors based on experts' assessment. The matrix was then scrutinized for transitivity, which accounted for an indirect relationship among factors. In simpler terms, if factor x influences factor y, and factor y influences factor z, then it implies that factor x also influences factor z. To account for transitivity, these indirect relationships were introduced into the reachability matrix by updating it iteratively. This involves changing "No" entries to "Yes" for each transitivity link.

(v) Level partitioning: For level partitioning the reachability matrix, when the intersection set and the antecedent set were found to be identical, a level was assigned to each cost factor. Once a level was assigned to a factor, it was excluded from further consideration in the subsequent iteration. This iterative procedure was repeated until levels were assigned to all the cost factors. Subsequently, driving and dependence power of the cost factors was analyzed using Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) analysis (Ahmad et al., 2019). This analysis categorized the cost factors into four segments—dependent, driver, linkage, and autonomous—based on their respective levels of dependence power and driving power calculated in the reachability matrix. The factors falling in *Autonomous* segment had both weak driving power as well as weak dependence power; those in *Dependent* segment had high dependence power and low driving power; factors in *Linkage* segment possessed high driving and dependence power. Lastly, the factors in *Driver* segment denoted high driving power and low dependence power

(vi) TISM based model: After level partitioning the reachability matrix, a model was formed based on the levels associated with each factor. The model depicts the interrelationships among cost factors, as required to address RO3.

5. Data collection and findings

5.1 Data collection through semi-structured interviews

In line with the ROs and as per the process described in the method section, data collection for this study began by conducting semi-structured interviews with members of the supply chain of green construction materials in India. To provide a varied and comprehensive perspective of the challenges (RO1) and cost factors associated with green construction materials (RO2) the research team made deliberate attempts to interview members playing different roles in the supply chain and also to reach out to members related to different green construction materials. Moreover, to cover more number of organizations, only one or no more than two respondents were interviewed from any organization.

A total of thirty-five semi-structured interviews were conducted by the team. The respondents of these interviews were associated with different stages of supply chains pertaining to green paints, green cement, environment-friendly bricks or blocks, and glass used in green buildings. While all the interviews were originally planned to be conducted physically, inclement weather conditions prevailing in the whole of Himachal Pradesh between the months of June to August (planned as the peak months of data collection) forced the research team to alter the plan and conduct many interviews in an online mode to ensure progress of the project.

Figures 2, 3 and 4 present descriptive data regarding the firms and respondents covered in the semi-structured interviews. On the whole, the respondents belonged to thirty-two firms. Figure 2 presents the distribution of these firms with respect to turnover. It shows that large number of participants belonged to the two extremes of the turnover categories. This is so because while some of these firms were large, established firms producing environment-friendly variants of cement, paints and glass, there were multiple small firms producing green bricks, blocks etc. Figure 3 presents a similar distribution in terms of the size of workforce for the firms.

Figure 4 presents respondents' profile in terms of their role or designation. As evident from this representation, the respondents covered in this study included founders of firms involved in green construction material supply chain, along with executives belonging to different positions in the corporate hierarchy.

Figure 5 presents data on the type of green construction material that the respondents dealt with. The majority of respondents worked in firms dealing with production/distribution/use of fly ash bricks and AAC blocks which are environment friendly alternates of conventional burnt clay bricks. In addition, the research team had also reached out to and interviewed executives from other industries producing green construction materials like cement, glass, paint, and steel.

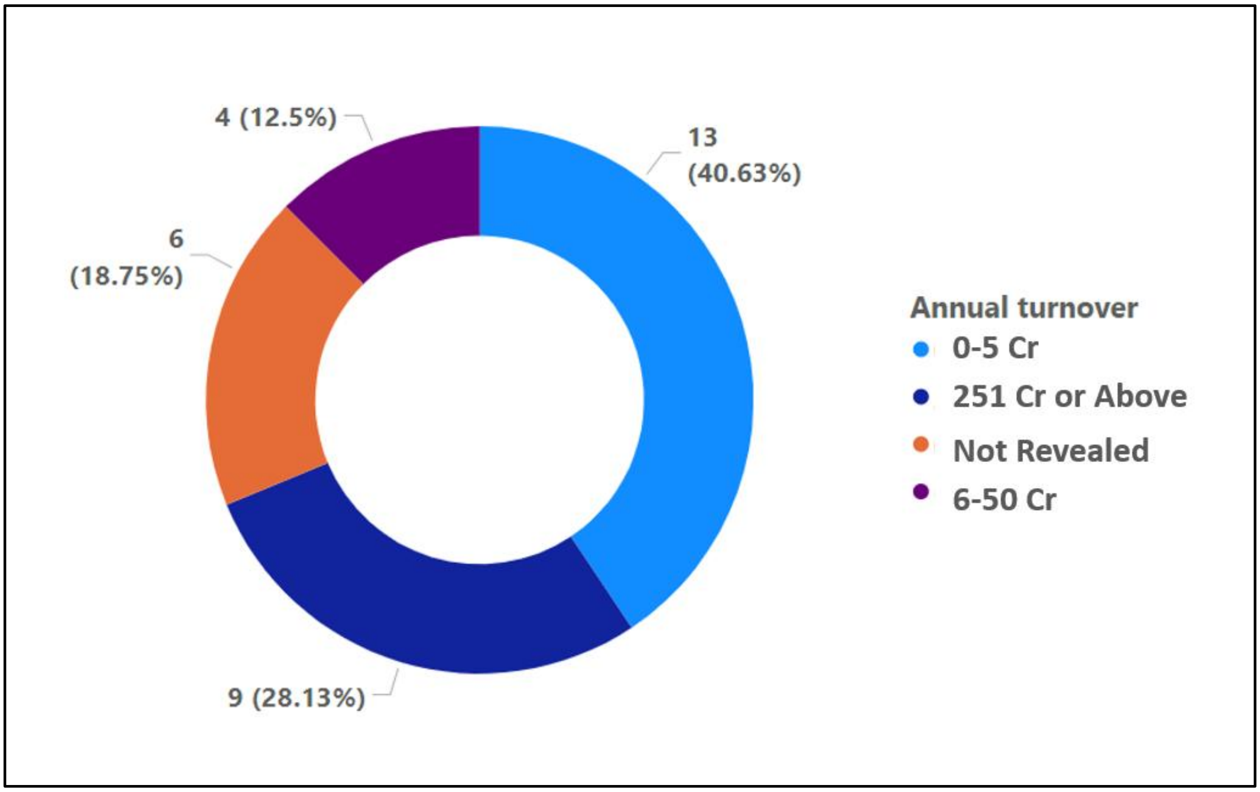

Figure 2 Distribution of respondents’ firms with respect to turnover

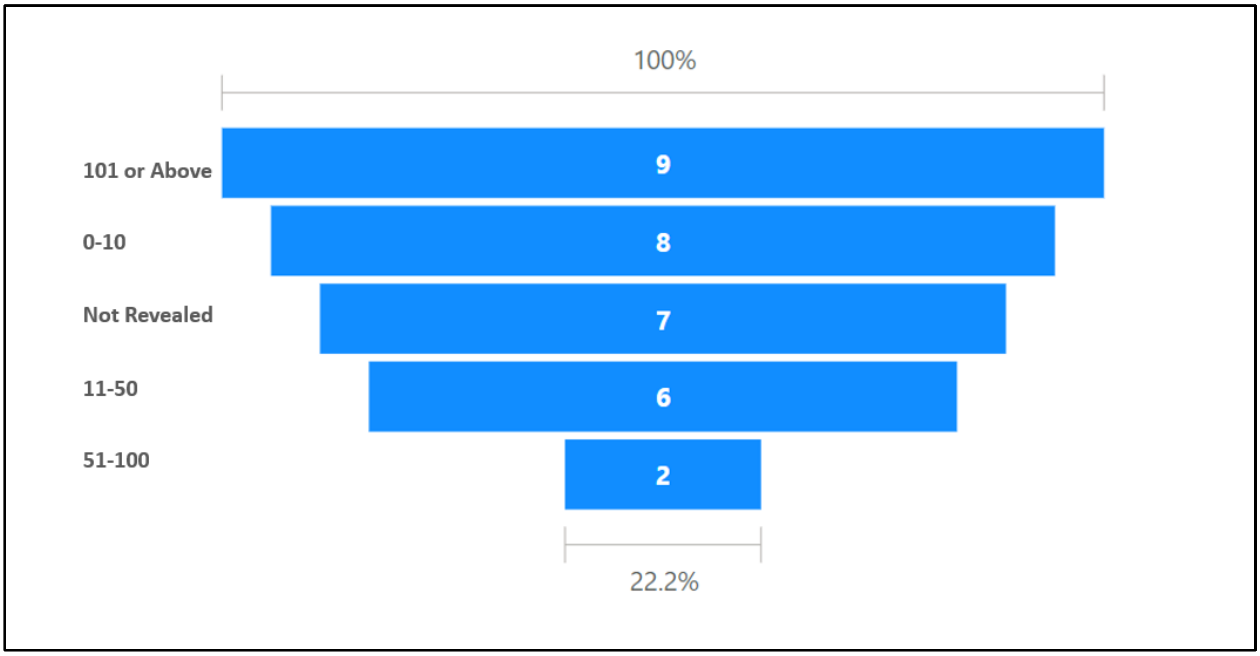

Figure 3 Distribution of respondents’ firms with respect to workforce

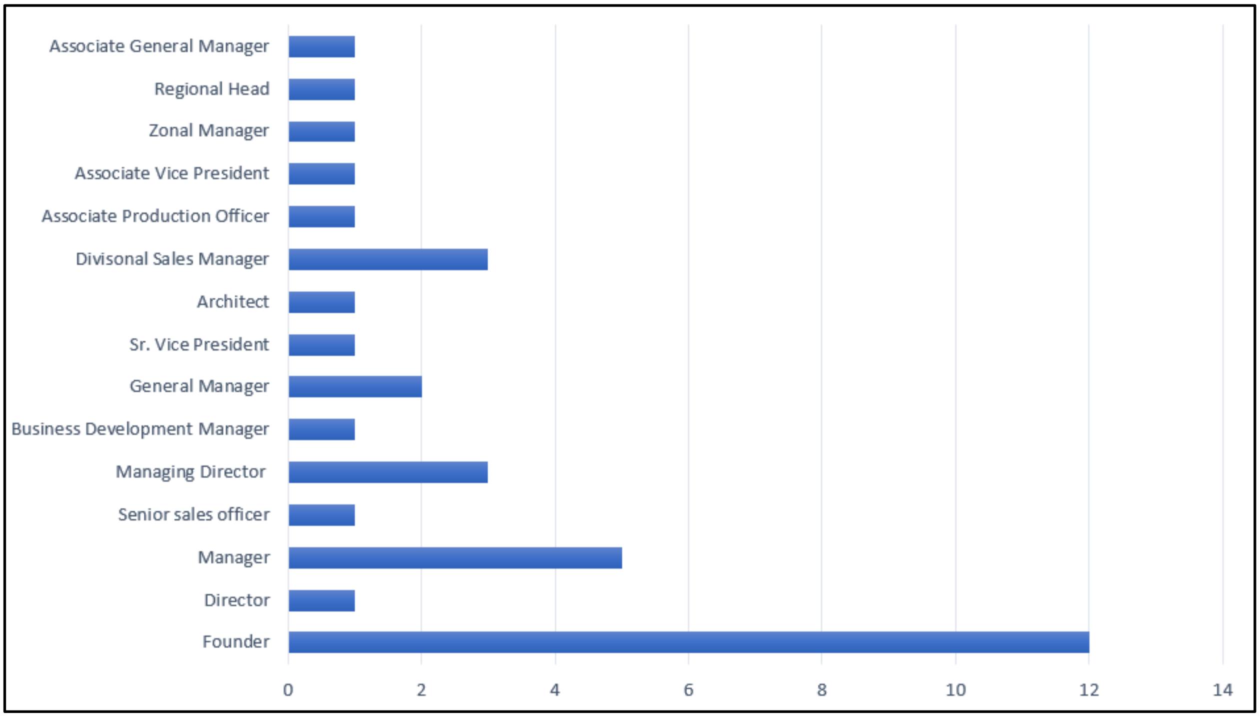

Figure 4 Respondents' role/designation

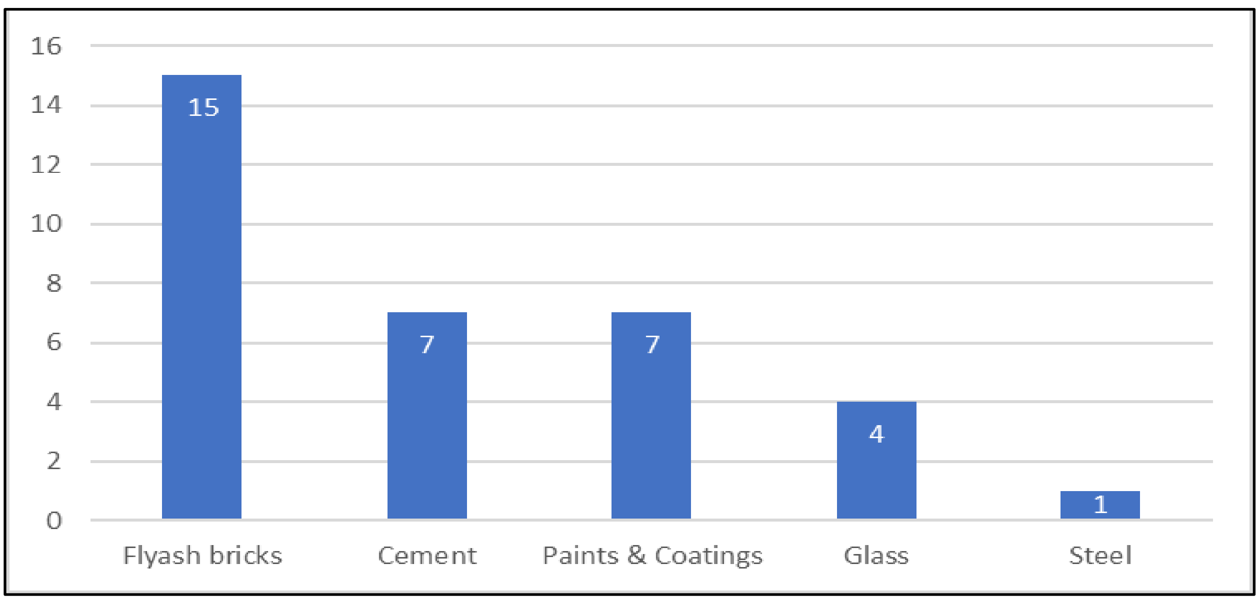

Figure 5 Green construction materials associated with respondents' firms

Figure 6 shows the respondents position as a member of the supply chain of the green construction. While the majority of the respondents were producers or manufacturers of green materials, some respondents belonged to other roles like raw material supplier, distributor, contractor and architect.

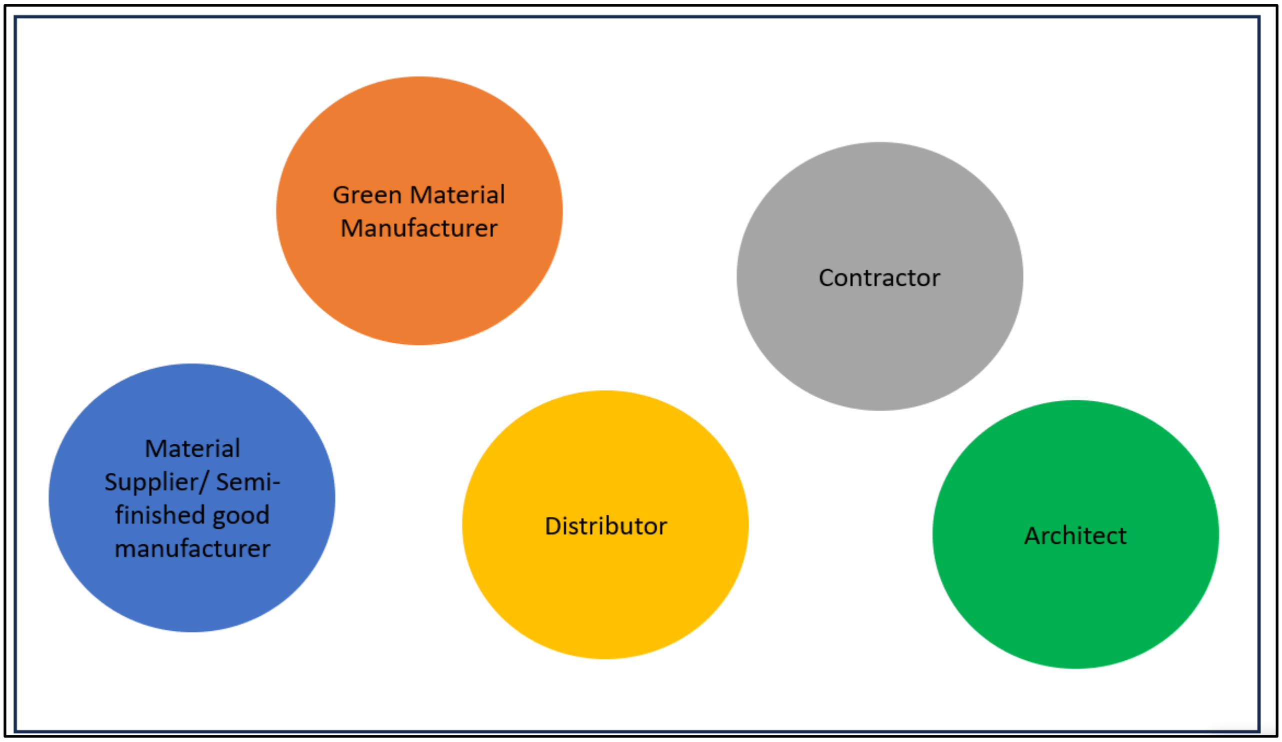

Figure 6 Role of respondents in green materials supply chain

5.2 Challenges in green construction material supply chain

Through the analysis of interview, we identified various challenges within the green material supply chain to address RO2. To do to, the interview recordings were transcribed and coded as a part of thematic analysis, the process of which has been described in previous section. Through this analysis we delineated five specific themes on challenges (TC1 to TC5). These themes comprised twelve subthemes on challenges (STC1 to STC12). The themes and sub-themes are presented in Table 1 and explained next.

5.2.1 External environment-related challenges

Many responses pertained to challenges relating the external environment in which the green construction material supply chain operates. This theme had three sub-themes (STC 1 to 3) relating to specific challenges originating from the external environment.

Table 1 Themes and sub-themes on challenges in green material supply chain

Themes (challenges)	**Sub-themes**
TC1: External Environment related challenges	STC-1: External Environment-fly ash supply related
	STC-2: External Environment-Demand related
	STC-3: External Environment-need for higher government support related
TC2: Operations related challenges	STC-4: Production Machinery related
	STC-5: Production process related
TC3: Inbound Logistics related challenges	STC-6: Weather related
	STC-7: Procurement related
	STC-8: Transportation related
TC4: Outbound logistics related challenges	STC-9: Delivery failure related
	STC-10: Third party logistics related
TC5: Marketing and Sales related challenges	STC-11: Raising customer awareness related
	STC-12: Product sales related

Manufacturers producing green bricks faced a significant challenge due to a shortage of or problems in acquiring a key raw material, namely, the fly ash. This was more so if thermal power plants stopped operations due to constraints like coal availability or any other reason during any time of the year. As Respondent#12 said

Fly ash is also not available throughout the year. It is only available when the thermal power plant is running.

Moreover, they expressed that some of the large intermediaries (traders) were procuring most of the fly ash since most of the power plants had fixed a minimum amount of fly ash to be procured and the small manufacturers were unable to procure fly ash in such quantity. Therefore, they had to buy it in smaller quantities at higher prices from the intermediaries. This was identified as a key challenge for green brick manufacturers. Highlighting this, respondent #12 illustrated

I do not participate in tenders [to procure fly ash from power plants] because the capacity of fly ash that needs to be purchased cannot be used solely by a fly ash brick industry. You need other products of fly ash too. So, I depend on some trader for fly ash.

Relating to this, a respondent also pointed out that fly ash used to be provided for free earlier and this facility allowed smaller manufacturers to obtain the same in required quantities. But, now the same is being tendered on price basis. This has created a challenge for these firms. Respodent#10 highlighted this by saying that

Earlier procurement of flyash was free, only handling charges, loading unloading had to be paid, but now fly ash procurement is very expensive. Now its charged at 800 Rs. ton. Every 31st march we have to fill a tender. We have quota of 250 tons.

Another external environment related challenge, identified commonly by many respondents, was related to lack of demand for green products. Many respondents highlighted this issue. For instance, Respondent#16 from the paints industry said:

We are making green paints but we are unable to find a good market for the product. Demand is not as per expectations in the Indian market.

Respondent#14, also from a paint manufacturing firm, attributed the lack of demand to low awareness among consumers:

…even consumers do not know the incentive from the government side in building a green building. If this could [be] communicated well, demand for our product may be far more. Our R&D team has tried and pushed down costs almost equivalent to other paints, but still, demand is not rising. It's like something is missed in between. The consumer is the main part where awareness is required and they even do not know about the sustainability part for the green products.

One of the green cement producers (Respodent#28) also highlighted this issue by saying that while the government is incentivizing the producers; it needs to do more to raise customer awareness.

The government is supporting builders in incentivization but they should also think for common people for same. The government should promote green housing through media and advertisement. So, people will know that what benefits they are getting and what society is getting from these houses.

Similarly, Respondent #6, a producer of fly ash bricks said that

I think the government should promote this product. Many people take concrete [and] flyash [bricks] as the same product. Differentiation should be created between these products.

Many respondents identified that while government schemes, policies etc. are already in place, there is a need for more support from the government and government agencies at central, state and municipal levels to facilitate production of green construction material. This challenge pertaining to varied issues as identified in respondents' quotes.

Respondent #9, a producer of green paver blocks using plastic waste, identified insufficient waste segregation as a challenge. He highlighted the need for more support from the municipal officials toward enhancing waste segregation as this could significantly improve recycling efficiency. He pointed out that

… Take the example of [name of a state], the government has spent so much on machines for segregation but the municipality segregates only a part of it and dumps the rest. ….There is a contract system for segregating waste at the municipality. …The lower government officials have a lot of work, they are overworked. Plastic segregation work should be a different department altogether.

Respondent #23, from a firm producing high performance glass for green buildings, identified competition from the cheaper imported glass as a challenge. He highlighted the need for government support in the form of anti-dumping duties to counter this challenge.

Glass is imported in India and it is cheaper. It is difficult to carry out business. We are able to produce at a higher cost. Government should increase anti-dumping. Import is a big challenge.

Respondent #5 highlighted another challenge pertaining to stocking river sand, which was hindering continuous producing fly ash bricks. He suggested that

Permission to stock river sand should be given by the government. It is not available every time. In the rainy season we cannot stock it because we have a limitation for stocking river sand.

Another common issue, which acted as a challenge in promoting green materials, was the lack of provisions mandating the use of green construction materials in India. Many respondents reasoned that if more government support could be provided in this regard, it shall address issues relating to demand and also create a bigger marker for green construction materials with more number of firms (buyers as well as producers). These aspects were evident in the following quotes.

Respondent#24 a green pain manufacturer suggested that

Some government norms are needed for the contractors for pushing water based products. Before constructing a building certain permissions are needed, then only norms for paints can be put. Bills should be asked for before constructing the building. Put a cap on use of oil-based paints.

Providing an example to this effect Respondent#13 said that

[Name of a state] Government is the first government to start cool roof policy which says any new buildings that are built will use green paints.

Respondent#4 from a firm producing fly ash bricks opined that

if governments made it [fly ash bricks] mandatory in their projects it will bring attention to normal customers about the importance of the product.

Similarly, Respondent#16, a new firm producing low VOC paints suggested that

In India, people are not very aware of specified VOC levels. Additionally, even from the government side, there are no mandatory rules regarding the level of VOC maintenance.

5.2.2 Operations-related challenges

Since many respondents in this study were producers of one or other green construction materials, they provided insights on various operational challenges that they face on recurring basis.

The most prominent operations related challenge was pointed out by producers of green bricks and blocks. It was related to the manufacturing equipment used in the production of fly ash bricks or blocks. There were two issues related to this. First, respondents pointed to a small set of manufacturers of such equipment. This in turn limits the availability of spare parts for the machinery and requires the material producers to stock spare parts because a just-in-time delivery is not possible in most cases.

Second, due to limited equipment manufacturers, getting timely services of a mechanic or technician from these firms is also an issue that contributes to the difficulties in sustaining the green material production business. Respondent #11 stated these challenges as

"We purchase [spare] parts well in advance to avoid rush [non-availability] at the last minute. Machinery as well as its spare parts have to be procured from Gujrat. Gujarat spare parts facility should also have distribution centres in our local areas. Every month maintenance cost is 50000, which needs to be addressed at earliest."

On the second issue of a technician he stated that

Machine has various motors. Its repair costs us very high. It's a complicated system. Its gear box is a challenge to handle. We usually have access to its spare parts from chandigarh as nearest and Gujarat as farthest. If I require exclusive services of engineer, it costs me very high. I need to take care about his stay, food etc for the duration he will stay. … You cannot call a person from Gujarat all the time for minor things.

In case of paint industry, a few respondents pointed to challenges in processing and application of green paints. They pointed to stringent temperature control requirements in the process of producing emulsions for low VOC paints. This not only results in significant electricity consumption but also a risk that minor temperature variations could lead to substantial costs for the company.

In this regards, Respondent #20 stated that

Most crucial part in my job is taking care of the temperature of reactor because a little inappropriate temperature and the whole batch is ruined. Storing the product is also a problem.

Respondent#22 described one more operational challenge in using such paints in colder regions. He stated that *During winters, specially here in [name of a city] paint cannot be done. It will change to flakes very soon. All paint will shed*.

5.2.3 Logistics (Inbound and outbound)-related challenges

Many respondents highlighted logistics related challenges, which if addressed, will lead to better availability and more competitive market for green materials. While some of these challenges could be applicable to the movement of goods in general, we are highlighting them here in the specific context of green materials as pointed out by the respondents.

Respondent #23 highlighted that the shared tracks for both passenger and goods trains posed a challenge for the timely delivery of green materials. He stated that

Train coverage is not good. Goods train runs at 25 km per hour, passenger train and goods train have the same route because passenger train always gets a preference. Because of slow speed we use other modes of transport and hence it turns out to be costly.

Respondents #3 and 8, from firms having production plants in hilly regions, highlighted that in hilly regions, the vehicles carrying raw materials (to produce green materials) are required to travel underweight for safety reasons and same is the case when the final green materials are sent to distributors and consumers. This leads to increase in the transportation cost and ultimately adds to the cost of the green materials.

Weather was also identified as a challenge for inbound logistics. Weather-related challenges significantly disrupt logistics, with heavy rains causing landslides that block roadways, preventing trucks from supplying raw materials to suppliers and impeding delivery networks.

Because there are fewer suppliers for the raw materials and final green materials, weather therefore creates a more severe disruption in supply chain of green materials.

One of the respondents drew attention towards long lead time and procurement challenges in obtaining OPC (cement). It is used by fly ash bricks manufacturers in the production of bricks. But this cement is not available as easily as the PPC. For this respondent, the firm had to procure OPC from a neighboring state, which presented logistical challenge and also contributed to higher cost. In this regard Respondent #11 stated

OPC cement is only available at [name of a state], other nearby plants are PPC. There is no plant in [name of another state where production unit is located] for OPC.

5.2.4 Marketing and sales-related challenges

There were a few respondents from marking and sales related profile who provided insights into challenges they face in persuading people or firms to procure green materials. Due to a lack of awareness, individuals or firms still prefer conventional materials for constructing houses. But, some respondents opined that this problem could still be addressed through the involvement of other stakeholders who assist customers in selecting construction materials. They highlighted that apart from the government policies and incentives, contractors and architects can play a crucial role in shaping or influencing end-users'/consumers' attitude towards adoption of green material by pointing to them the lifecycle benefits of these materials in term of protecting the environment and also financial benefits that could accrue to the users (like lower electricity charges).

However, resistance or inflexibility of these *influencers* towards incorporating green materials in design and construction could become a major obstacle in promoting the uptake of green materials. This, in turn, leads to a lack of acceptance by consumers, thereby reducing spending on green alternatives.

Highlighting this issue, Respondent #6 expressed his concern about low acceptability of fly ash bricks among customers.

…when we were pitching 100-200 customers 1 or 2 were converted but we never got repeated

orders. Even Mason workers were never interested, we tried a lot but they said clay brick is a traditional brick and highly acceptable at customer level. He will make his home once in lifetime and if he has 0.1% doubt regarding the product, he will not accept the product. We tried our best to convince him but he may have enquired about it from a mason [or an], architect ......

Another challenge pointed to by a few respondents was related to low quality of green materials as produced by some firms due to the pressure to offer competitive prices vis-à-vis conventional materials in the market. As suggested by Respondent #5, such practice dent the reputation for all other green products in minds of the consumer. Explaining this, Respondent #5 said

... because many plants do not produce bricks up to the mark and seeing the quality customers think this product is of poor quality. So, quality control and more awareness is needed.

5.3 Cost factors associated with green construction materials

In line with the RO2, through thematic analysis of interview transcripts we identified various cost factors associated with the green material supply chain. Four categories of cost and nine specific cost factors were identified (Table 2). These categories pertained to fuel and energy, logistics, marketing and production, and raw materials and helped understand the cost premium associated with green construction materials.

Table 2 Cost factors associated with green construction materials

Themes (cost categories)	**Sub-themes (specific cost factors)**
TC1: Fuel and Energy related factors	CF1: Expensive Energy
	CF2: Expensive Fuel
TC2: Logistics related factors	CF3: Mode of transport Restrictions
	CF4: Costlier Transportation
TC3: Marketing and Production related factors	CF5: Costlier Marketing and advertising
	CF6: Expensive Processing and packaging
TC4: Raw material related factors	CF7: Costlier Raw material
	CF8: Higher inventory cost
	CF9: Increase in Raw material prices

Notably, while some of these factors were specific to the type of green material under consideration (in an interview), others appeared more commonly across responses. On the whole, addressing these factors shall go a long way in reducing the cost of production of green materials and thereby directly contribute to making green housing more affordable.

5.3.1 Fuel and Energy-related factors

Many respondents highlighted that costs associated with fuel and energy required for production of green materials have been consistently increasing and these two collectively constitute a considerable share of the total production cost. While fuel costs are those relating to procuring, transporting and using fuel (like coal or liquid fuel) for the production process, those pertaining to energy are primarily the cost associated with electricity consumed in the production process.

Highlighting the impact of these factors, Respodent#15, a senior executive in a (green) cement manufacturing firm stated that

We are facing challenges in two major components in our production fuel and electricity …Coal is a major component in the production of cement. It consist 30% of our transportation cost and it way to expensive for us…..Fuel [overall] almost consists of 50% of production cost….Our cost is increasing due to increasing liquid fuel cost that further increases our transportation cost….

These statements concur with report of the World Coal Institute which states that "coal is used as an energy source in cement production. Large amounts of energy are required to produce cement. Kilns usually burn coal in the form of powder and consume around 450g of coal for about 900g of cement produced" (World Coal Institute, n.d.).

Interestingly, cement being a major raw material used in the production of other green materials (like green bricks and blocks), increasing cost of cement was found to have a cascading impact on the cost of these materials too. For instance, Respondent#2 from a firm producing green blocks asserted that "*80% [of production] cost is due to cement"* and that if cement cost could be brought down, it will reduce the production cost of the blocks and also present the possibility to reduce the prices. He commented "*Make cement cheaper and the problem [of reducing the prices of blocks is] solved*".

Similarly, Respondent #19 from a glass manufacturing firm pointed to the expenses associated with electricity charges due to energy-intensive nature of the production process of glass.

In our industry, thermal power is highly required to make glasses. It increases our electricity cost. If I could substitute that, it would help in reducing cost.

5.3.2 Logistics-related factors

In the analyzed responses logistics cost was identified as one of the key cost factors. As explained next, an increase in logistics costs was found to be attributable to challenges stemming from transportation over long distances through costlier modes of transport, and also those incurred in importing raw materials from international markets.

For the producers of green bricks and blocks, apart from the cost of fly ash, its transportation was also identified a major cost factor. This was an even bigger concern for producers that were not having thermal power plants in their vicinities. Hinting at this, Respondent#11 stated that

Fly ash costs us Rs 900 per ton at my plant. This includes majorly transport cost which is a major concern to be addressed.

For some of the green products transport costs were a concern as part of the raw material had to be imported. Indicating this, Respondent#18, from a green glass manufacturing firm said

Silica is the major raw material used in production. However, there are frequent raw material shortages in the country. Then we have to import them and it's too costly…. transport charges are so volatile with the fuel charges.

Similar was the issue highlighted by a respondent from a firm that is producing green steel. He stated that already high logistics costs were further exacerbated by the expensive imports of scrap required to make green steel.

"As we need scrap to make green steel, domestic scrap is not collected properly. So, we have to import from the international market, it is incurring the highest cost."

Highlighting that transport cost comprise a major share of total production cost, a few respondents stressed on the need for transportation subsidies for firms producing green construction materials. They suggested that this could be a way to make green materials cheaper for the end-user and thereby increase the demand. Respondent #4 stated

Transportation subsidies will help us in a great way. Our product will be available at competitive prices and eventually an increase in sales can happen.

In some cases, respondents highlighted that while rail transport could be cheaper, they were still using other modes due to slower speed of goods train or lack of rail connectivity near the production plants. The longer time needed for transportation through goods trains have made many firms relying on costlier road transport that further added to the production cost. This problem was highlighted by Respondent #23

Train coverage is not good. Goods train runs at 25 km per hour, passenger train and goods train have the same route because passenger train always gets a preference. Because of slow speed we use other modes of transport and hence it turns out to be costly.

5.3.3 Marketing and Production-related factors

Many of the challenges related to production, marketing and sales, as described in the previous section of this report, also contributed to the increase in cost of green materials. Most importantly, a large number of respondents had highlighted the lack of awareness among customers and their resistance to switch to green materials from the conventionally used ones. Consequently, the firms involved in selling these green materials had to incur higher costs in increasing customer awareness and to acquire new customers.

Respodent#13 from a green paint manufacturing firm highlighted these efforts and the challenge to gain customer buy-in despite the promotion campaigns. He stated that

…we run TV advertisements in different languages. …. Pushing the product here is a problem. Distributor buys on trust. Convincing a customer for environmentally friendly product is difficult

One of the respondent highlighted the activities that they were doing to promote green materials and raising customer awareness at the local level through promotional activities, while also pointing additional financial burden of such advertisement. This Respondent #10 stated

"[for the] Hollow brick we are making. We do advertisements using an autorickshaw that goes

in colonies, homes. … we have to bear costs for doing [these] advertisements."

Similarly, Respondent#4 from a firm that was manufacturing fly ash bricks highlighted the efforts and money invested in promoting these bricks as alternate to the conventional bricks and that the firm had to step the production due to lack of demand. He stated that

We ourselves worked hard to market this product by running advertisements on cable TV. We highlighted various benefits like termite proof, temperature control, less water retention and less need of plaster during wall making, etc.

For most of the firms involved in producing green bricks and blocks, there existed costs related to the machinery and its maintenance & repair. Additional costs had to be incurred due to limited availability of spare parts necessitating stocking spare inventory, and those relating to costlier maintenance due to fewer trained technicians. This problem was highlighted by Respondent #11 who stated that

We purchase parts well in advance to avoid rush at the last minute [during breakdown]. … Gujarat spare parts facility should also have distribution centres in our local areas. Every month maintenance cost is 50000, which needs to be addressed at earliest."

Machine has various motors. Its repair costs us very high. It is a complicated system. Its gear box is a challenge to handle. We usually have access to its spare parts from chandigarh as nearest and Gujarat as farthest. If I require exclusive services of engineer, it costs me very high. I need to take care about his stay, food etc for the duration he will stay.

5.3.4 Raw material-related factors

For most of the green material manufacturing units, raw materials cost remains a larger chuck of the total product cost and many respondents pointed to various reasons due to which the raw materials are getting costlier, thereby increasing the prices of green construction materials.

There were many reasons cited by respondents on the cost associated with raw materials. For instance, Respondent#11 pointed out that for their case, they had to buy sand from a specific authorized supplier that was taking benefit of its position. He pointed to a "*monopolization for* *procurement of sand from single point [name of specific place] spot. They are giving us for Rs 28, which again costs high to us."*

In another case of a producer of tiles using plastic waste, Respondent#9 highlighted the problem associated with getting the raw material (waste plastic) in segregated form. He indicated that the waste received from the municipal corporation was not fully segregated and this necessitated employing additional manpower for segregation purpose which added to the cost of the raw material and the final product (paver tiles or blocks). Highlighting these issues, he stated that

I recycle every plastic such as bottles, lays packet and single use plastic to manufacture blocks. Every plastic requires a different melting point as they differ in bonding. The municipality does not provide properly segregated waste…. I segregate different waste material and some are used for tile making while others are sold. Ragpickers sell it for a higher cost because waste is already cleaned…. Major cost driver is labor that works before processing starts, segregation is time taking and expensive.

As highlighted in the previous sub-section, similar was the situation in case of green steel production where segregated steel scrap was not available to manufacturers, which compelled them to import it at higher prices.

As regards to a significant increase in raw material prices, most evident impact was on fly ash bricks producing firms. Respondents from these firms pointed to the fact that while earlier fly ash was being provided to them at negligible prices, its prices have increased substantially over the last few years. In addition, many producers of fly ash seem to have fixed quota for purchase due to which many small-scale manufacturers of fly ash bricks are not able to procure it directly from the producers and have to approach traders (intermediaries) to procure fly ash in smaller quantities at higher rates.

Emphasizing these issues, Respondent#10 said that

Earlier procurement of fly ash was free, only handling charges, loading unloading had to be paid, but now fly ash procurement is very expensive. Now its charged at 800 Rs. ton. Every 31st march we have to fill a tender. We have quota of 250 tons Proportionately according to tender *filled the fly ash is given.*

On similar lines, Respondent#12 highlighted that

I do not participate in tenders because the capacity of fly ash that needs to be used cannot be used solely by a fly ash brick industry. You need other products of fly ash too. So, I depend on some trader for fly ash.

Main margin is in purchase. Fly ash, if available at low cost, the overall cost [of green material] can be reduced. Alternative materials can be used. I tried using other alternative but then quality suffers.

Despite the increase in cost of raw materials, the selling prices of green materials have not kept pace due to stagnant demand and low acceptability of green materials. This dissonance is leading to a decline in profits and putting a strain on the financial viability of small enterprises involved in producing green materials. These challenges are evident in the following statement of Respondent#12

Stone dust and sand prices are increasing every year and there is lack of acceptability in consumers for the increasing price. Same is the case with fly ash.

On similar line, *Respondent#30,* a producer of green bricks also pointed out similar issue

No one pays attention to prices in clay bricks, but in fly ash, they see prices. We are providing fly ash even at 4.5 per brick, still people are not purchasing. Earlier 20% quota was fixed to get fly ash for free of cost to the manufacturer of the fly ash bricks, but it is not now. Earlier, it was announced that fly ash within 300 km of the area would be available free of cost. But it stopped. It should be continued again.

Few respondents also revealed that in some cases they had to keep higher inventory of raw materials to ensure the smooth continuity of operations. This is due to uncertain availability of these raw materials throughout the year. For example, Respondent #6 stated that "*Procuring aggregate and dust is difficult. We have to stock stone dust …"*.

Similarly, a few respondents pointed to the need to carry inventory of green materials that further add to the cost. Though this cost may be applicable in case of any finished goods, what makes it peculiar in the case of green material is high demand uncertainty. This issue was exemplified in the following statement of Respondent#

We are processing at the minimum profits. Inventory cost is also high…. Additionally, we have to see the fast service and products being available to the customer at any point in time. Then, again with demand uncertainty, it is difficult to maintain inventory.

5.4 Understanding interrelationships among cost factors and developing hierarchical model

To understand the interrelationships among the nine cost factors (RO3), TISM was used as per the process described in the method section. As its first step a binary matrix (Table 3) was developed using experts' inputs. From this, a reachability matrix (Table 4) was developed which shows the transitivity (indirect) relationships and driving and dependence power of each factor.

Table 3 Binary matrix based on relationship between cost factors

Cost Factor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	1								
2	1	1	1	1	1	1	1	1	1
3			1						
4			1	1	1	1	1	1	1
5					1	1			
6						1			
7			1				1	1	
8								1	
9		1			1	1	1	1	1

The reachability matrix was then partitioned into different levels that are finally used to depict the hierarchy of cost factors. Tables 5 to 9 show the five iterations performed to partition the cost factors into five levels.

Table 4 Reachability Matrix

Cost Factor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Driving Power**
1	1									1
2	1	1	1	1	1*	1*	1	1*	1	9
3			1							1
4			1	1	1*	1*	1	1	1	7
5					1	1				2
6						1				1
7			1				1	1		3
8								1		1
9		1*			1	1	1	1	1	6
Dependence Power	2	2	4	2	4	5	4	5	3	

Table 5 Level partitioning of reachability matrix (iteration 1)

Cost Factor	**Antecedent Set**	**Reachability Set**	**Intersection**	**Level**
1	{1}	{1,2}	{1}	
2	{1,2,3,4,5,6,7,8,9}	{2}	{2}	I
3	{3}	{2,3,4,7,9}	{3}	
4	{3,4,5,6,7,8,9}	{2,4}	{4}	
5	{5,6}	{2,4,5,9}	{5}	
6	{6}	{2,4,5,6}	{6}	
7	{3,7,8}	{2,4,7,8,9}	{7,8}	
8	{8}	{2,4,7,8,9}	{8}	
9	{3,5,6,7,8,9}	{2,4,9}	{9}	

Table 6 Level partitioning of reachability matrix (iteration 2)

Cost Factor	Antecedent Set	Reachability Set	Intersection	Level
1	{1}	{1}	{1}	II
3	{3}	{3,4,7,9}	{3}	
4	{3,4,5,6,7,8,9}	{4}	{4}	II
5	{5,6}	{4,5,9}	{5}	
6	{6}	{4,5,6}	{6}	
7	{3,7,8}	{4,7,8,9}	{7,8}	
8	{8}	{4,7,8,9}	{8}	
9	{3,5,6,7,8,9}	{4,9}	{9}	

Table 7 Level partitioning of reachability matrix (iteration 3)

Cost Factor	Antecedent Set	Reachability Set	Intersection	Level
3	{3}	{3,7,9}	{3}	
5	{5,6}	{5,9}	{5}	
6	{6}	{5,6}	{6}	
7	{3,7,8}	{7,8,9}	{7,8}	
8	{8}	{7,8,9}	{8}	
9	{3,5,6,7,8,9}	{9}	{9}	III

Table 8 Level partitioning of reachability matrix (iteration 4)

Cost Factor	Antecedent Set	Reachability Set	Intersection	Level
3	{3}	{3,7}	{3}	
5	{5,6}	{5}	{5}	IV
6	{6}	{5,6}	{6}	
7	{3,7,8}	{7,8}	{7,8}	IV
8	{8}	{7,8}	{8}	

Table 9 Level partitioning of reachability matrix (iteration 5)

Cost Factor	Antecedent Set	Reachability Set	Intersection	Level
3	{3}	{3}	{3}	V
6	{6}	{6}	{6}	V
8	{8}	{7,8}	{8}	V

Based on levels derived for each of the nine factors and their driving and dependence power, the factors were divided into four categories (Figure 7). The hierarchical model, showing interrelationships among the nine cost factors is presented in Figure 8.

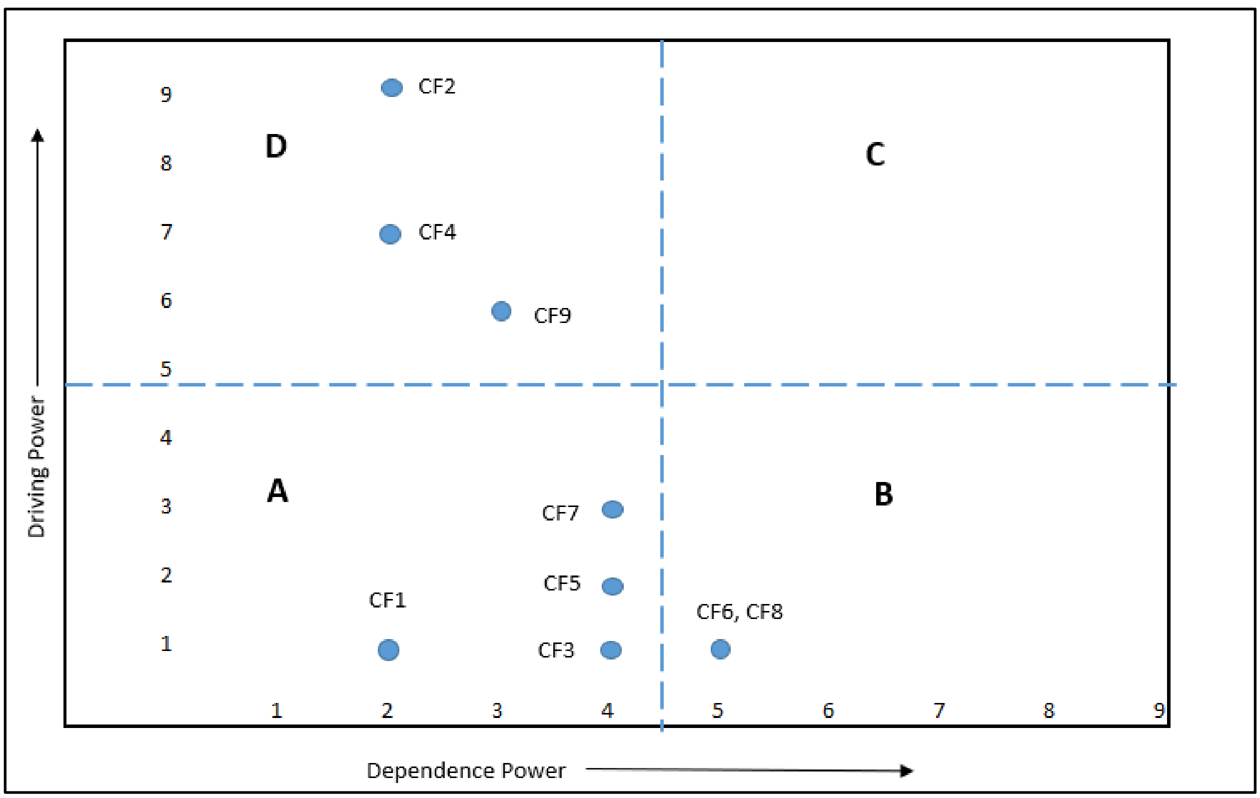

Figure 7 Classification of cost factors

The model (Figure 8) shows all the cost factors arranged in the order and with interconnections as ascertained by TISM. It attempts to present the complex relationships that collectively drive the cost of green materials. While most of these relationships have been touched upon in previous sections pertaining to challenges and cost factors associated with green construction material supply chain, this model visually represents these relationships.

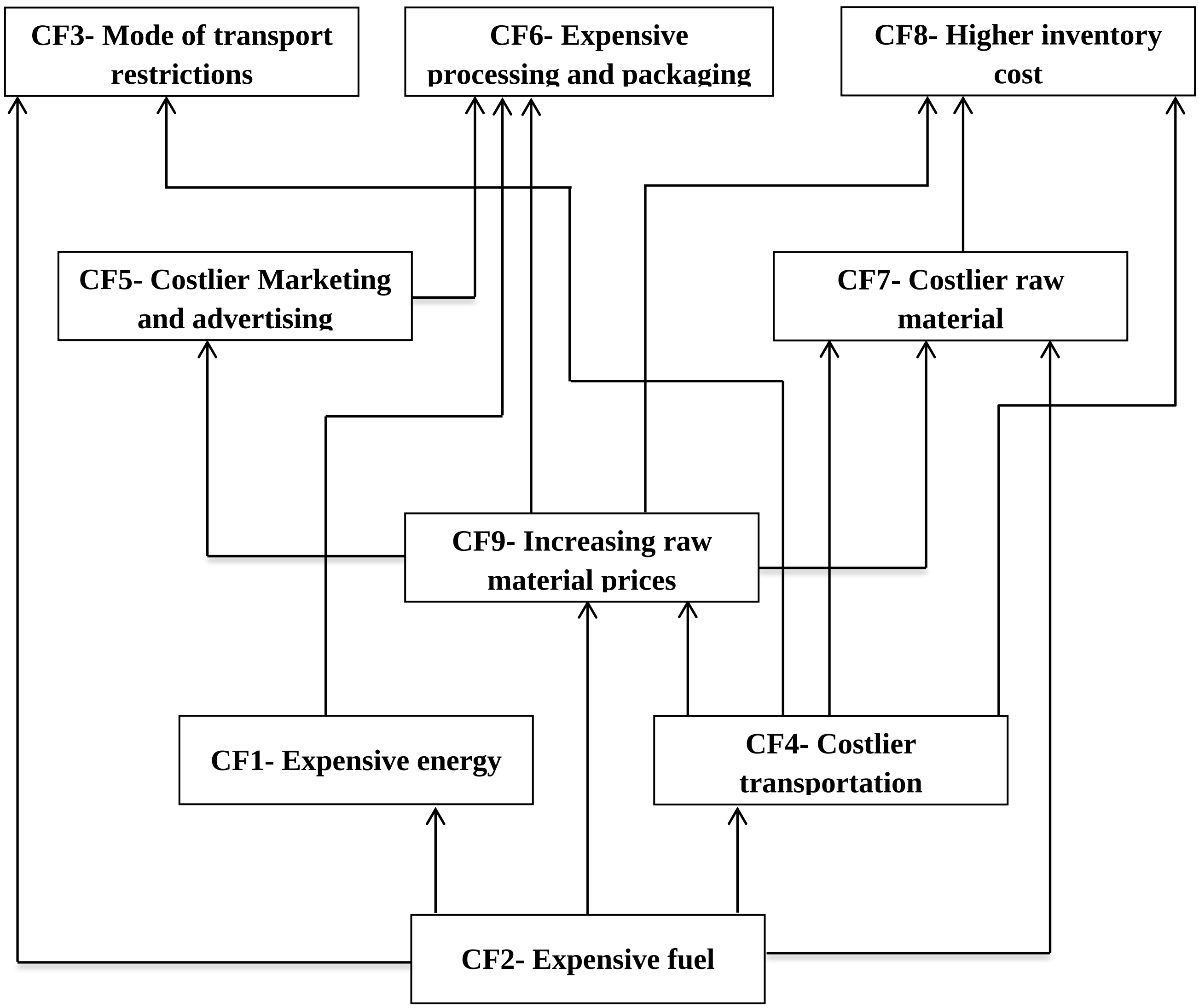

Figure 8 Model depicting interrelationships among the cost factors

The cost factors placed at the bottom of the model, namely, expensive fuel, energy and transportation (CFs 1, 2 and 4) seem to be driving most of the other cost factors. Logically, this makes sense in that increase in fuel prices, which are often driven by global macro-economic conditions, makes transport (CF4) of raw materials and final products costlier (especially road transport, which is the most common mode as indicated by many respondents). It also makes energy expensive (CF1), which in turn, contributes to the cost of processing and packaging (CF6) for the green materials.

High transportation charges, including in situations explained earlier wherein the raw materials was imported (like in case of green steel and glass), lead to expensive raw materials, CF7. This also contributes to a consistent increase in raw material prices (CF 9), as pointed out by many respondents. More so, in the case of fly ash bricks the significant increase in prices of raw material was due to charges being levied in the procurement of fly ash and the provision of quota being fixed by fly ash producers. Costlier raw materials and its unavailability throughout the year pose a challenge and call for procuring in advance. This, coupled with uncertain demand of the green materials, lead to higher inventory cost (CF8) for the producers and make the green material costlier for the end users.

Lack of awareness about the lifecycle benefits of green materials to 'demand' use of green materials, and lack of enthusiasm among many contractors and architects to switch to green materials lead to an overall lack of demand for these environment friendly materials in the market. To overcome this lack of awareness and/or resistance, firms have to incur higher marketing and advertising expenses (CF5), as compared to conventional materials which are all well-known to and tried and tested by all these key stakeholders of the construction industry.

6. Conclusion and recommendations

This research was conducted to address the broader aim of making green housing more affordable. Since green construction materials are a major contributor to the cost premium associated with green housing, this research study devoted specific attention towards understanding the challenges faced by members of green materials supply chain in the India and the cost factors associated with green materials.

To this end, the research team conducted thirty-five interviews with practitioners belonging to thirty-two different firms. These firms were members of supply chain of different green materials (like fly ash bricks, green glass, steel, cement, and low VOC paints). This variety of respondents provided a holistic picture of the green material supply chain. While most of the respondents belonged to firms involved in the production of green materials, others were from firms essaying the role of supplier of raw or semi-finished material, distributor, architect, or contractor. Systematic analysis of the responses provided by these practitioner-respondents provides insights into the green material supply chain in India and address specific research objectives pertaining to the challenges (RO1), cost factors (RO2), and interrelationships among the cost factors (RO3).

As regards to RO1, five specific themes, comprising twelve sub-themes, pertaining to the challenges in green material supply chain have been identified. These revealed that the supply chain members are encountering challenges relating to external environment due to difficulties in procuring fly ash (to make fly ash bricks), gaining to access to segregated municipal waste (for producing paver blocks or tiles), and scrap steel (to make green steel). These problems were further aggravated by a lack of awareness among end-users regarding specific environmental and economic benefits of green materials, especially on a lifecycle basis.

In fact, the lack of awareness among end-users has been one of the recurring issues across interviews, cutting across respondents from different firms dealing with different green materials. Also, this challenge has been found to further manifest in the form of or indirectly lead to many other challenges for supply chain members, like limiting the demand and overall market size of green materials, resistance from ‘influencers’ like architects and contractors to switch to green materials, lesser number of suppliers for raw materials and production machinery (and trained technicians therein), and uncertain demand for finished products (green materials) leading to higher inventory. Though many respondents highlighted their efforts to increase demand by promoting green materials through advertising activities aimed at mainstreaming the use of these materials at B2C and B2B levels, they believe that impacts of such efforts, mostly targeting areas in and around production facilities of the firms, have been minimal at best.

Most of the challenges identified in this study had a bearing on the four categories of cost and nine specific cost factors that were identified through the thematic analysis of interview responses. For instance, the challenge pertaining to lack of end-user awareness and lower demand called for higher expenses in marketing and advertising activities and also contributed to higher inventory costs. Similarly, challenges pertaining to raw materials manifested in terms of costlier raw materials and significant rise in raw material cost over the years. Owing to significant rise in the cost of fly ash, the latter was found to be a bigger problem in case of environment friendly bricks or blocks that incorporate fly ash as a key constituent. Another challenge contributing to increased cost of raw material was rising fuel prices that directly impact transportation and production cost, the former one more so in cases where any raw material is imported and where on-site fuel burning is required in the manufacturing processes. These complex interrelationships among the nine cost factors were captured in the hierarchical model (figure 8) developed using TISM.

Addressing the challenges in green material supply chain and the cost factors identified in this study call for initiatives by different stakeholders. To this effect we had captured opinions from the experts during the survey and also from interview respondents. These opinions also touched upon the role of government incentives, subsidies etc. Some excerpts from suggestions provided by experts and a few interview respondents are presented in Table 10. Building on the same, we advance the following recommendations.

Since a lack of end-user awareness seems to be the elephant in the room, this issue must be addressed on priority. To this end, government agencies (at central, state and municipal levels) and various industry associations should take more initiatives to increase awareness regarding the environmental and economic benefits of green housing and the importance of using green materials to develop green housing. These efforts should specifically target small-scale firms operating as contractors and architects, who could, in turn, educate individual and corporate end-users regarding green housing and green materials, and encourage them to perceive the premium associated with first cost of green buildings as an ‘investment’ that would be returned in terms of financial benefits (lower electricity and water expenses, for instance) and better health (for instance, through non-toxic, low VOC paints and better indoor air quality). Increased consumer awareness through such initiatives could expand the market for green housing, which would provide impetus to the demand for green materials.

Table 10 Suggestions and/or recommendations captured during survey and interviews

Sl.	Suggestion/recommendation captured during survey and interviews
1	*Current incentives focus more on the CAPEX in construction. In addition to that, incentivizing OPEX would reduce lifecycle cost of residential housing and thus encourage more home buyers to select such projects. (i)Input cost subsidy to encourage alternate energy usage.* *(ii) Tax subsidies (GST) for recycling*
2	*The government is supporting builders in incentivization but they should also think for common people for same. The government should promote green housing through media and advertisement. So, people will know that what benefits they are getting and what society is getting from these houses.*
3	*In my opinion, to an extent, there has been a good influence of incentives. However, to make it more effective, the Government should start tightening the curbs on non-green products, especially when green alternatives are available (for example, when sand mining was banned, construction companies started to use crusher dust more frequently).*
4	*The current initiatives have minimum impact. They [government agencies] should first set more recycling facilities by which increase production and strictly enforce usage [of green bricks] in the government projects first and then make an act to use by common public*
5	*Other than creating additional infrastructures, subsidies, government should organize training programs, campaigns to provide vision and percolate the ideas to grassroots level for developing consumer base [for green materials]. Atma Nirbhar Bharat is a good model.*
6	*Government should subsidize the whole process of plastic waste recycling because if we use landfill plastic waste for making construction materials like interlocking pavers , curb stones, Road divider , floor tiles , interlock wall bricks etc. then it will help to reduce unwanted and discarded plastic waste dumps and storage sites*
7	*If government promotes green products form waste material direct or indirectly this effort will save a large amount of money and will generates lot of jobs in green products market*
8	*Governments need to fix the rate of aggregate, stone dust, and fly ash as they are the primary component of green building products. ... To make it more affordable, the price of raw materials needs a cut down…..the government needs to take into consideration [that] the green products is the future of new generation buildings and provide the business owner with lower raw material rates and encourage the manufacturers.*
9	*Raw material that is available in other countries at low cost should also be available in India at the same cost.*
10	*The government should strictly ban the clay bricks from being used in the government owned buildings. Fly ash is not available directly to the manufactures. The intermediary should be omitted*
11	*Government should make strict norms with the use of green paint as a must, not as a choice. Only then customer is going to use it otherwise they may not shift to green products. Same thing happened in the Europe and this worked out well.*
12	*the government should have an ecosystem for waste where they could collect all the waste, pre-process it, and provide it to the cement industry for utilization This could help in a circular economy with recycling and better utilization.*
13	*Power plants should have a team for handling fly ash distribution.*
14	*…even consumers do not know the incentive from the government side in building a green building. If this could communicate well. Demand for our product may be far more.*
15	*Customers who use green glasses in their buildings must get some incentive in the form of tax reduction, or anything so that they would be motivated to use such products in their building.*
16	*Transportation subsidies will help us in a great way. Our product will be available at competitive prices and eventually an increase in sales can happen.*

Doing so also appears to be important in light of suggestions captured in Table 10 which highlight that while the producers of green materials are generally aware of various government incentives being extended to them, this ‘push’ alone is insufficient to create a market demand for green materials. Therefore, more efforts towards increasing the user awareness about the benefits of green housing and green materials, and the incentives being offered by the government could ‘pull’ up the demand. This is in line with recent research evidence based on signaling theory which suggests that rising consumer awareness on sustainability issues can increase their ‘willingness to pay’ for green products and services, especially among the Gen Z (Gomes et al., 2023).

Moreover, to increase end-users’ willingness to pay for green materials, more and more green material manufacturers should be made aware of the process and encouraged to obtain certifications for their products. During the interviews it was gathered that while most of large corporations, like those producing green paints and cement, were aware of and had green product certifications, small-scale producers, like those making fly ash bricks or blocks, paving blocks, were either not aware of or believed that the process of obtaining certification was too cumbersome to be undertaken by those firms.

With regards to addressing the issue of costlier raw materials, the producers of fly ash (power plants) need to be sensitized of the problems being faced currently by the small-scale producers of fly ash bricks, and ensure that they are able to procure fly ash directly from the plants at low prices. As many respondents had highlighted, the tendering-and fixed quota-based system for the supply of fly ash may be re-looked into. Similarly, in the case of paver blocks or tiles that use plastic or other waste, the cost of raw material for the tile makers can be reduced by extending more assistance through local municipal corporations in supplying segregated plastic waste to the manufacturers. Municipal corporations can create separate cells for segregation purpose. Such efforts may not only create employment at the bottom of the pyramid (like rag pickers) but also help bring down the cost of tiles.

Finally, to address the factors pertaining to fuel, and energy, which occupied bottom positions in the TISM model (Figure 8) and were driving (influencing) many other cost factors, switching over to renewable energy would be a clear and preferable option to bring down the production cost. In fact, many respondents from small-scale firms stated that their firms had considered the use of solar energy for production purpose to bring down the production cost. Most of them were even aware of incentives offered by government in this regard. Yet, many firms had not made this transition yet as they were not sure of the pay-back period of using renewable energy for production, and needed concrete data to make decision of switching to solar power. Therefore, an opportunity exists to facilitate transition of green material manufacturers towards renewable sources like solar through handholding by industry associations and government agencies. Such transition would not only bring down the product cost, but also ensure that these materials become even 'greener' through further reduction in their carbon footprint.

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