Insulating Sandwich Panels using Waste from Leather & Shoe industries and Rubber tyres with GFRG panels

A

synopsis

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Submitted by

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1. Introduction

1.1 Preamble

Housing-related issues have attracted global attention for the emergence of houses due to the increase in population. According to a UN prediction, by 2050, 64.1% and 85.9% of the developing and developed nations respectively will be urbanized. The rise in urbanization requires extensive construction, which consumes natural resources like sand, silica, lime, iron, etc, and creates major issues like:

i. **A large amount of waste generation.**
ii. **The need for rapid construction of houses.**
iii. **The creation of concrete jungles.**

Concrete and brick have the ability to provide strength, durability, and longevity. Concrete has excellent workability and the nature of shaping itself. Bricks are economical, have low maintenance, and are recyclable and reusable. Due to these reasons, concrete and bricks are the dominant construction materials.

Concrete and bricks are made using natural materials which tends to deplete natural resources. This is one of the major disadvantages of using these conventional materials. The major ingredient of concrete is cement which has negative environmental impacts. The cement industry is a major producer of carbon dioxide, a potent greenhouse gas **[**1**].** Brick manufacturing kilns emit toxic fumes containing suspended particulate matter rich in carbon particles and having high concentrations of carbon monoxides and oxides of Sulphur.

Natural resources are limited on earth and using them in uncontrolled ways will lead to the depletion of these resources. Depletion occurs when these resources are consumed at a higher rate than that replacement. Another issue is waste generated like municipal solid waste, agro-industrial waste, mining industries waste, and hazardous waste.

Due to urbanization and to accommodate a large number of people, there is a requirement for land. This leads to deforestation which in turn creates an imbalance in nature and shows a drastic change in the climate. Extensive heating can be observed in urban areas as these lands are densely populated due to which more heat is produced which in turn becomes a new challenge to deal with the buildings need to be breathing cells rather than concrete-heating jungles. To reduce the heating effect, insulating materials can be used in construction.

Today the volume of waste generation is becoming a cause of serious worry. One of the solutions is to use part of the generated waste as building construction material. This solution will resolve to some extent issues like waste, overutilization of natural resources, and formation of new construction materials with the usage of waste.

The solid waste consists of yard trimming, newspaper, appliances, clothing, bottles, rubber, foam, electronics, leather shavings, etc. Rubber waste and leather waste form a significant part of solid waste. It has been reported by **Chittella et al [2]** that 9.2 million tons of rubber and leather waste were generated in the US. The major source of rubber waste is automobiles. Sources of leather and foam waste are the shoe industries. Around 1.7 million tons of rubber waste is recyclable and the remaining is either landfilled or incinerated**.**

All engineers, especially civil engineers have a responsibility to introduce practices that have a lower impact on the environment. Effectively there should reduce deforestation, overutilization of land and resources, waste generation, etc. Hence the concept of sustainable development has evolved with the usage of high performance of materials with waste. To create a material by using waste we need to first know about the amount of waste generation, waste types, and its potential to be used in construction.

1.2 Waste generation

A study by **The World Bank [3]** reported that more than **2 billion tons of municipal solid waste annually**, at least 33% of which is not managed in an environmentally safe manner. Worldwide, waste generated per person per day averages 0.74 kilograms but ranges widely, from 0.28 to 4.54 kilograms as shown in fig 1.

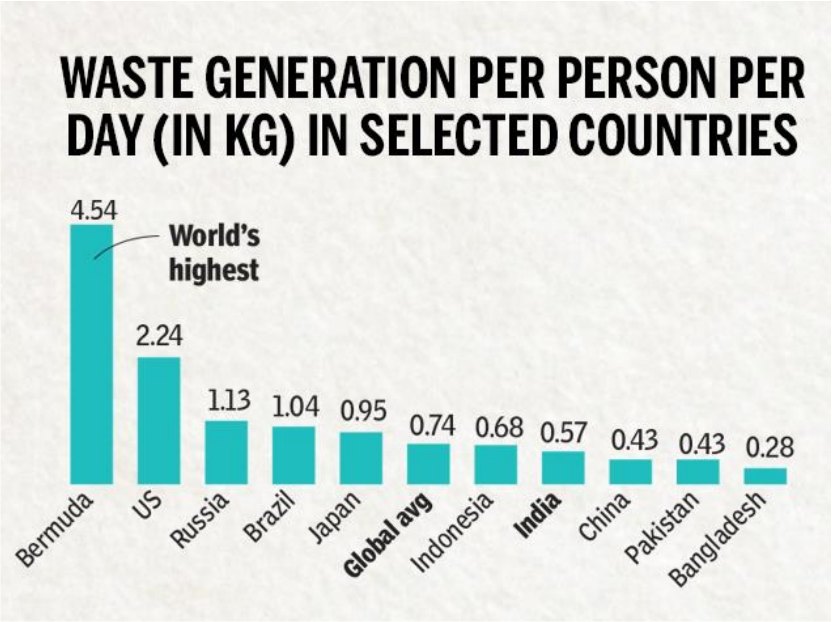


Fig. 1 Waste generation per person per day [3]

1.2.1 Overall solid waste management in India

The following data is detailed in **the Annual report on solid waste management, CPCB Delhi [4]**

Table 1: Overall solid waste management status [4]

SI No.	State	Solid Waste Generated (TPD)	Collected (TPD)	Tested (TPD)	Landfilled (TPD)
1	Andhra Pradesh	6766	6140	1059	203
2	Arunachal Pradesh	285.65	223.56	Nil	127.72
3	Assam	1271.305	922.4115	41.6625	880.749
4	Bihar	4334	Yes	Not	No
5	Chhattisgarh	1650	1650	1385	265
6	Goa	188.88	180.38	148.91	15.59
7	Gujarat		10755	6924	3831
8	Haryana	5231.9	4808.8	1620.6	3188.2
9	Himachal Pradesh	393	354	230	127
10	Jammu & Kashmir	1518.91	1464.65	540.19	No
11	Jharkhand	2188.97	1847.38	731.76	1179.68
12	Karnataka	12258.2	10011	4489	Not
13	Kerala	3521	880	1837	Not
14	Madhya Pradesh	7980	7193	6431	762
15	Maharashtra	22945.256	22779.31	16037.26	6907.98
16	Manipur	265	192.4	103.57	88.63
17	Meghalaya	153.18	119.19	9.64	Nil
18	Mizoram	348.19	313	278.4	Nil
19	Nagaland	306.1	255.9	24	6
20	Odisha	2208.6	2123.3	202.4	1920.9
21	Punjab	4477.542	4413.952	2112.457	2301.495
22	Rajasthan	6659.38	6475.9	1190.93	5112.66

23	Sikkim	74.7	74.6	12.56	62.032
24	Tamil Nadu	14228	13955	6620	6765
25	Telangana	9285	9270	6070	593
26	Tripura	411.32	380.8	253.6	127.2
27	Uttarakhand	1610.942	1481.057	716.637	-
28	**Uttar Pradesh**	**14468**	**13955**	**5395**	**0**
29	West Bengal	13980	12062	916	334
30	Andaman and Nicobar	121	115	50	65
31	Chandigarh	450	450	179.61	270.39
32	DDDNH	184	191	97	DNH-Not Provided Daman- Not Provided Diu- 30
33	Delhi	10470.57	10466.57	5193.57	5276
34	Lakshadweep	32.55	32.55	11.44	Nil
35	Puducherry	580	517	61	456
	Total	**150847.1**	**146053.8**	**70973.2**	**40863.2**

1.2.2 Solid waste management data

A report from **CPCB [4]** give an account of solid waste management for the past five years (2015-2020) in India, examined and the following are the observations.

1. The solid waste generation has been calculated for the past five years and graphically represented in fig 2. The data are shown in per capita solid waste generation over the past five years.

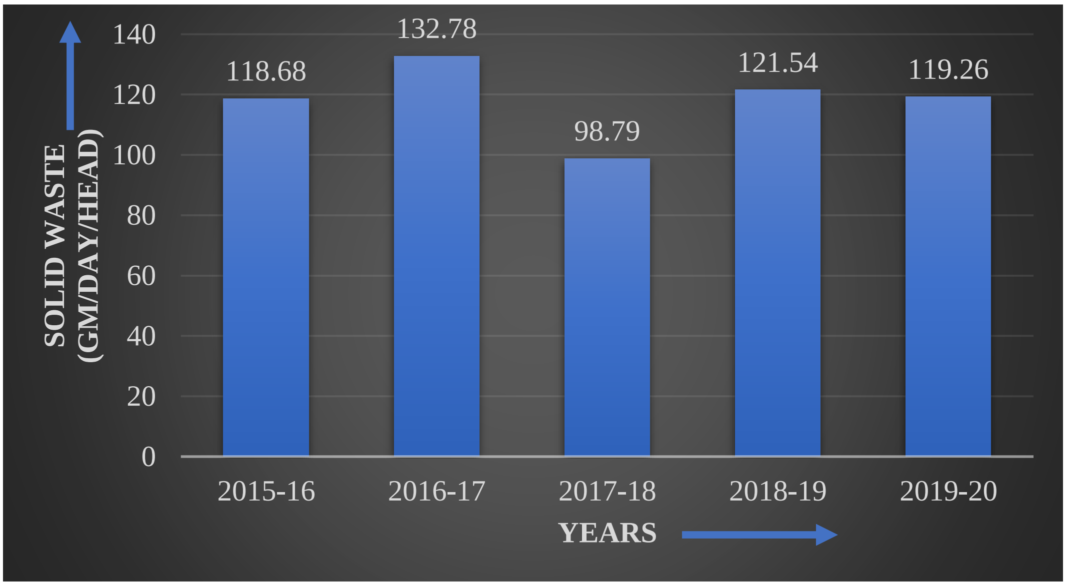


Fig. 2 Solid waste generation [4]

2. The percentage of solid waste processed during the last 2015-20 is illustrated in fig 3. An increasing trend in the percentage of solid waste processing was observed during the past five

years wherein the percentage of solid waste processed has increased from 19% in 2015-16 to 47% in 2019-20.

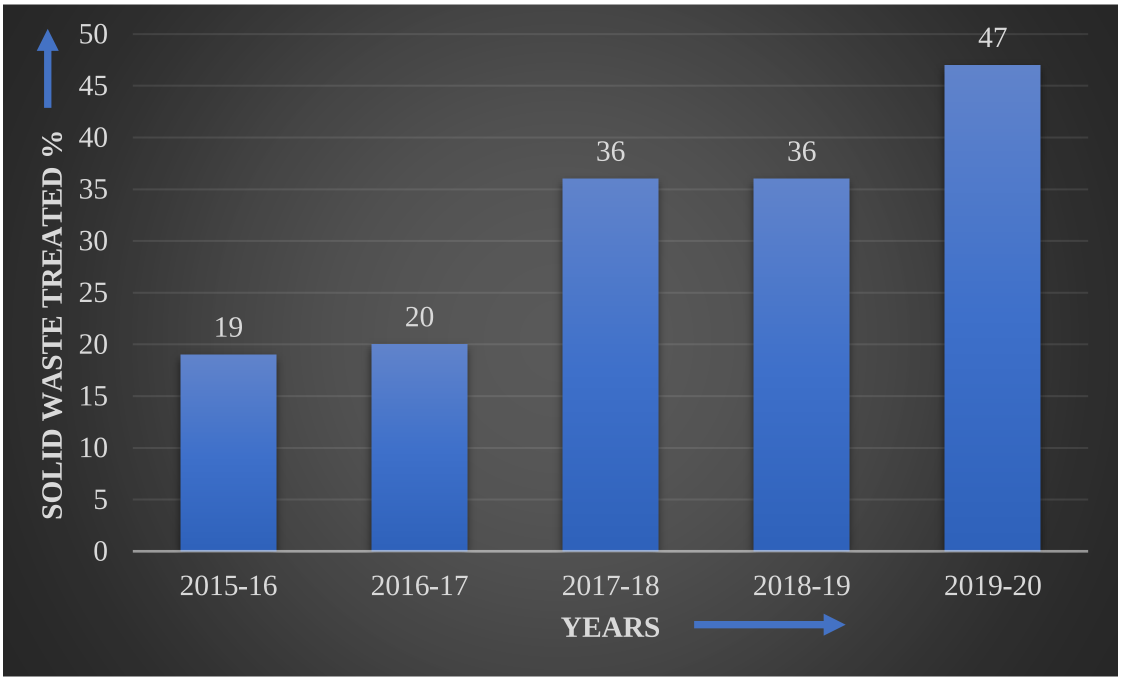


Fig. 3 Solid waste treated % [4]

3. The percentage of solid waste landfilled during 2015-20 is illustrated in fig 4. A decreasing trend in solid landfilled was observed during the past five years wherein solid waste landfilled has decreased from 54% in 2017-18 to 27% in 2019-20.

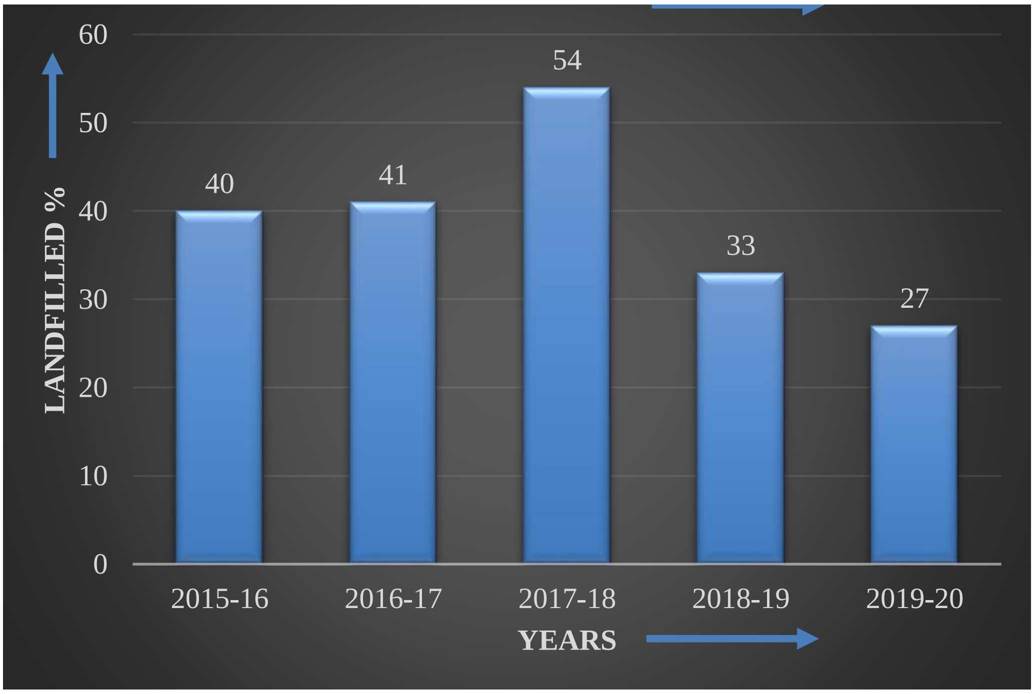


Fig. 4 Solid waste landfilled % [4]

4. Urban India generated 1,43,449 metric tons of municipal solid waste per day in 2014-15 is illustrated in fig 5. Of this waste 40-60% is organic and 10-20% is recyclables. This indicates there is a clear waste minimization potential of 14,344 – 28,689 metric tons per day through recycling and recovery.

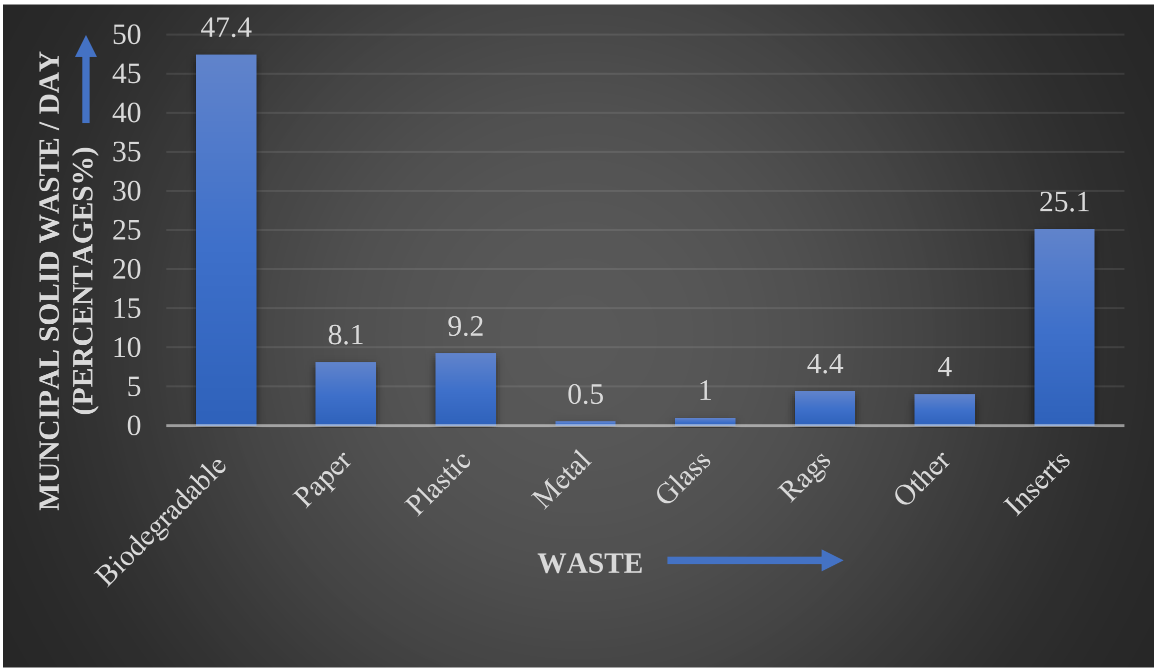


Fig. 5 Municipal solid waste per day % [4]

1.2.3 Solid waste processing in different states [4]

The percentage of solid waste treated in different states/UTs is illustrated in figure 6. It is found that the highest percentage of solid waste treated is in Chhattisgarh (84%). U.P treats less than 40% of its waste.

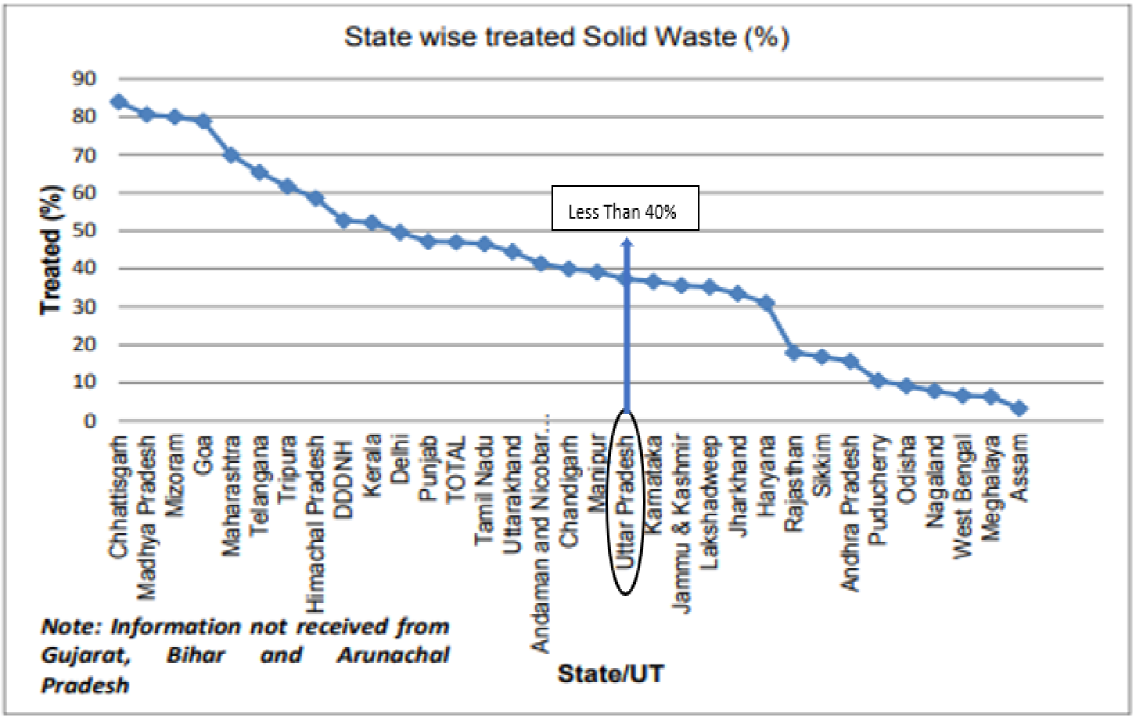


Fig. 6 State wise treated Solid waste (%) [4]

In conclusion of this, a large amount of waste is generated and according to the CPCB report, some part of it is treated and processed whereas the remaining part of it is landfilled or disposed of in other manner. Landfilling and disposal without proper treatment/processing lead to soil degradation and other forms of pollution.

The proposed research aims to utilize some of the waste generated in construction activities, leading to a reduction in the total quantum of waste, thus reducing environmental degradation.

2. Literature Review

2.1 Introduction

Increasing urbanization has led to a drastic increase in infrastructure. Simultaneously, mountains of waste have been generated. We need to mold our research to reduce the consumption of natural resources and to recycle waste in an effort to minimize the impact on the environment. Recent research has focused on the utilization of waste from different sectors in the construction industry. Materials like fly ash, plastic, rubber, glass, ceramic, construction waste, rice husk, bamboo fibers, leather, e-waste, etc., are partially replacing conventional materials used in construction.

There is an emerging need for construction materials that can reduce the energy consumption of the heating and cooling effect of living spaces in buildings. The literature review presented below is focused on the use of waste in construction, especially in insulation, insulating panels, fabrication methods, properties of sandwich panels, and their determinations.

Ashokan Pappu et al [5] have investigated waste generation in India and its recycling potential in building materials. This study states that 960 million tons of solid waste are generated as byproducts of industrial, mining, municipal, agricultural, and other processes.

Jacob Coleman et al [6] have given the concept of a prefabricated wall panel made up of straw and wool. This panel provides high insulation and they are made to increase the uptake of straw and wool. They conceptualized the use of biodegradable and recyclable materials in construction materials. In this research, they found the potential use of pure wool insulation in prefabricated wall panels and combined it with compressed straw insulation. Exterior gypsum sheathing is provided in these panels.

Ravijanya chippaagire et al [7] have researched on by-products of agriculture industries and made use of co-fired blended ash (CBA) in making bricks and insulating wall panels. The brick size of 230×100×80 mm is made from agro-waste. The insulating sandwich panels are constructed, these panels have an insulating layer in between two concrete panels. The insulating layer is of PUF and concrete as a partial replacement for CBA. These panels give excellent thermal resistance.

Abdul Basir Awan et al [8] describe the structural behavior of precast concrete sandwich panels (PCSPs) containing recycled tyre crumb rubber core under uniaxial compression and compared it with Expanded Polystyrene (EPS) foam. The use of crumb rubber in concrete improved the properties such as crack resistance, impermeability, toughness, freeze-thaw resistance, and damping ratio. But it decreased the compressive strength, modulus of elasticity, bond strength, tensile and flexural strength. These panels possess positive results on dynamic loadings.

Kassahun G. Sellassie et al [9] In the study they experimented with the thermal conductivity of rubber shreds. The apparatus used in this paper is hot plate apparatus. The experiment reveals that the thermal conductivity of shreds depends upon the temperature, size, and density of shreds.

A. Benazzouk et al [10] In this paper an investigation of thermal conductivity of construction material containing waste rubber particles is tested. In this cement is replaced by waste rubber shreds in 10%, 20%, 30%, 40% by volume. The rubber shreds are less than 1mm and a composite is prepared. Samples of 100×100×100mm were prepared. The thermal conductivity of the sample has experimented through Transient Plane Sources (TPS) technique.

Gregory Woltman et al [11] have experimented of the thermal properties of insulated concrete sandwich panels with fiberglass shear connectors. In this study, the thermal resistance (R-value) of panels are found by using the hot box approach.

A. Teklay et al [12] used leather waste with plant fibers. In this, he made use of natural rubber and fiber. According to his study, it is estimated that 20-30% of leather is discarded as waste from leather industries. Different combination of leather is made in the proportion of 10%, 20%, 30%, and 40%. The properties like tensile strength, elongation at break, water absorption, water desorption, and tensile strength were compared. The components like wall partitions, roofing, and others can be made through this.

M. Barbanera et al [13] investigated the use of recycled leather cutting waste-based boards and study the thermal, and acoustic hygrothermal properties. It was found that the thermal conductivity of the panel measured by means of small hot box apparatus is about 1.10 -0.11 w/(mk) at 33°C-35° C. its acoustic properties is also good i.e., transmission loss varies according to thickness. It was also found that wettability and permeability properties is quite low. It also shows a lower environmental impact with respect to a conventional solution.

Changhai Peng et al [14] investigated thermal and energy characteristics of composite structural insulated panels consisting of glass fiber reinforced polymer and cementitious materials. It was investigated from the study that the thermal properties of traditional structurally insulated panels were improved by using glass fiber reinforced plastic. It was found from this investigation that these materials described above are better than steel panels as they better thermal absorption properties. They are also energy-saving materials and are also economical. It was found from the study that the thermal resistance value for this material i.e. R vale for GFRG IS 3.447 m^2 K/W which was better than steel

H Lakrafli et al [15] investigated the thermal conductivity of leather and carpentry wastes. It was found from this research that this waste is being used as filling material and is useful in decreasing the thermal conductivity of the material with which it is used. It was also found that these waste materials have shown better results when used in a dry state. And it was also investigated from the research that these wastes have proved to be economical. As per research thermal conductivity of these waste material vary according to the proportion of waste i.e. 0.034-0.040 w/(mc), 0.046-0.051 w/(mc), and 0.076-0.083 w/(mc).

Taher Abu-Lebdeh et al [16] investigated the thermal conductivity of rubberized gypsum board. It was found from the study that the average thermal conductivity of rubber material is found to be 0.187 W/mk-0.248 W/mk which was 18 to 20% lower than the control specimen. It was found that using rubber with gypsum density was reduced but thermal conductivity decreased with increase in rubber size. It can also be inferred from the study that this material is found when used with rubber shows better performance and hence can be used in drywalls. Although the density and thermal conductivity were low but it can be utilized as a lightweight coating to improve the thermal performance of walls.

Sara Gutiérrez González et al [17] investigated sustainable Lightweight Prefabricated boards based on Gypsum Mortar with Semi-Rigid Polyurethane Foam Waste. This work focus on the physical-mechanical characterization of a new lightweight plate for use in internal ceilings, and the demonstration of its viability on an industrial scale, which would permit its application in the future. This study addresses the problem of management of plastic waste (mainly Polyurethane foam waste). Waste PU foam **(0-0.5 mm, the real density of 1080 kg/m3, bulk density of 72 kg/m3)** is mixed with gypsum and water, and analysis was done. It was found from this study that there is no significant improvement in bulk density, but the flexural strength result complies with the tiles results. The use of prefabricated gypsum in the study has encouraged sustainability in the management of PU foam waste.

Muhammad Wasim et al [18] investigated from his study that the Structural performance of prefabricated glass fiber concrete floor (GFC) panels are better than compressed fiber concrete (CFC). It was found that structural analysis for glass fiber concrete of various thicknesses of floors and loading conditions shows superior performance over compresses fiber concrete. It was found that the lower thickness of the floor made of glass fiber concrete shows better performance from a structural and deflection point of view. It was found that when floor thickness of 30mm and 40 mm was taken then deflection was found to be under serviceable limits i.e., compared to compressed fiber concrete it was found that prefabricated glass fiber concrete was 11.5% much serviceable. In addition to this, it was found to be cost-effective and labor savings.

Thiago Moreira Flores et al [19] analyzed the Characterization of Animal Leather Dust Waste from the Footwear Industry and by scanning electron microscopy described the intertwining of the leather fibers with pores in the matrix prepared during the experiment. Therefore, there is evidence of the interaction of the residue with material like concrete. They stated that leather waste is suitable for reuse/treatment using the technique of stabilization/solidification with matrices of materials such as cement.

K. Ravichandran et al [20] studied the use of chrome leather particles with recycled rubber which was found to improve the consumption of scrap rubber powder in natural rubber formation. Polymer composites based on leather waste as fillers are reported to be useful for many applications such as in construction materials, flooring materials, heat, and insulating boards, air permeability, etc.

Ibrahim Almeshal et al [21] performed a review of research on waste plastic and used the recycled plastic as fine aggregate in cementitious composition. He reviewed the papers to analyze the different waste plastic and their mixing tendency with construction material.

Meifeng He et al [22] studied the composite honeycomb sandwich panel structure. Honeycomb sandwich structure combines high flexural rigidity and bending strength with low weight. To achieve the maximum flexural rigidity and bending strength, the satisfying weight condition of the honeycomb core weight is 50–66.7% of the weight of the whole honeycomb sandwich panels. They proved through the experiment and comparison with the theoretical values.

Md. R. Karim et al [23] address the effective utilization of waste like slag, fly ash, rice husk ash, palm oil fuel ash, ash from timber as a supplement of cement or constituent of concrete will effectively save energy as well as sustainable construction.

Sandesh Kiran. S et al [24] elaborated on the ASTM-specified test methods for evaluating the physical and mechanical properties of cores and sandwich composites.

2.2 Literature Gaps

The rate of consumption of natural resources (clay, sand, stone, gravel, wood, etc) by the construction industry has increased. According to the World Watch Institute, the construction industry consumes 40% of the world's usage in raw stones, gravel, and sand and 25% of its virgin wood per year. To achieve sustainability, waste can be used to replace traditional materials in some applications.

One of the ways in which waste can be used is in the replacement of walls with sandwich panels which would leads to the following advantages:

- constructed and assembled rapidly
- reduced time of construction
- ease of transportation due to reduced weight
- reduced waste generation
- improved insulation

Earlier research addresses the usage of waste in different components of construction like walling panels, roofs, bricks, roads, etc. different types of waste are available, and they have been studied and described by **Ashokan Pappu et al [5]**.

Waste like wool and straw, co-fired blended ash, Polyurethane foam (PUF), recycled tyre crumb rubber, natural rubber, plant fiber, and leather waste have been used in various aspects of construction **[6,7,8,10,12,13,15,16,19]**. At present, the use of sandwich panels is very limited and further research needs to be carried out to eliminate research gaps, some of which are listed below:

1. A systematic study of the Sandwich panel using waste and its properties is not available.
2. An exhaustive study of the possible use of many waste materials in construction has not been made.
3. Techniques to combine different waste materials and determination of their properties have not been studied exhaustively.
4. Though the use of some waste materials in walling system has been studied, this needs to be extended to other materials and forms of walling system.
5. Research has shown that usage of some waste materials results in reduced energy consumption **[23]**. Such studies need to be extended to other waste materials also.
6. The long-term durability of waste needs to be studied to know its effectiveness in construction.
7. The quality of construction depends on a number of factors. The usage of waste in construction leads to the improvement of some and the deterioration of others. Additional research is required to determine what combination of materials could improve some

parameters that define the quality of construction.

Out of above research gaps, the present study aims to make a systematic study of Sandwich Panels with the specific intent of combining different industrial waste components to obtain improved thermal insulation.

3. Proposed Work

Advancement is taking place in different building units and one of these is walling system. Walls are the basic unit of infrastructure and cover a large part of a building. The advancement in walling system is due to different factors.

1. Initially, the walls were load bearing and required walling blocks to be large enough to withstand the load of the ceiling and super structure.
2. Research moved toward RCC-framed structures, leading to non-load bearing walls which could be made thinner, thus increasing the usable floor space
3. The increasing need for accommodation in small urban areas led to the development of construction techniques to build high-rise structures. This required the structures to be made as light as possible, thus developing newer areas of research.
4. At present, overutilization of natural resources in construction is a major issue. One way of reducing the use of natural resources is to use industrial and other waste in construction. As reported by CPCB, a large percentage of waste is not properly treated for disposal. Some part of the raw waste could have the potential to be used in construction.

In view of the present direction of research in construction, the present work proposes to make use of waste in the fabrication of sandwich panels.

As Agra is one of the major hubs of the leather industry in India, it is proposed to explore the possible use of waste generated by these industries in the fabrication of sandwich panels for thermal insulation. It is reported by **Mohd Faheem et al [25]** that Agra produces 65% of the total domestic consumption and 28% share of the total footwear export for India. As it is the hub of manufacturing, it is also becoming a hub of waste generation.

In addition to large industrial houses, the production of footwear is also done in a large number of homes as cottage industries. Waste generated by large industries is often disposed of with proper treatment, but the waste generated in cottage industries is largely dumped without any treatment as can be observed in the photographs below (Figure 7, 8). Frequently, such waste accumulates over a period of time and is then incinerated (Figure 9), leading to pollution of the surrounding air, water, soil, aquifer, etc. Due to the continuous burning of waste, the walls have now turned black. The overflooded drainage can be seen in (Figure 10) due to excessive waste dumping.

Fig. 7 Location: Open drain near Agra Fort Station

Fig.8 Location: Near Agra Fort Station

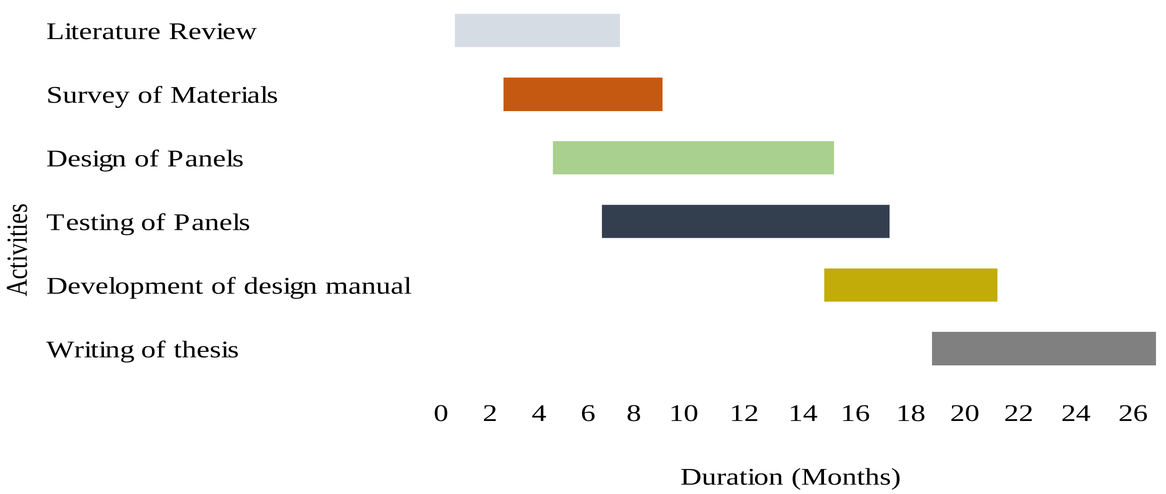
Fig.9 Location: Cheel Ghar Baluganj, Agra

Fig.10 Location: Bijli Ghar, Agra

3.1 Aim

To develop Insulating Sandwich Panels using waste leather, rubber, foam, etc. from the Leather industry, shoe industries, and tires as packing between GFRG panels.

Table 2: Expected timeline for the research



3.2 Objective

- To identify the appropriate proportion of rubber, leather, and foam waste to develop the insulating layer.
- To fabricate the sandwich panel by using the insulating layer between gypsum sheets.
- To test the sandwich panel for insulation properties.
- To develop a manual for the manufacturing and assembly of these panels.

3.3 Methodology

The methodology to be followed for the proposed research is given below:

1. Detailed analysis and estimation of waste generated by shoe and leather industries in and around Agra and their possible collection.
2. The method of processing the waste collected will be devised. Any equipment needed for the procedure will be procured.
3. Fabrication of panels using different processes/methods will be explored and the products would be tested for identification of the most effective method. One of them can be by sandwiching the core layer of waste in between glass fiber reinforced gypsum (GFRG) sheets. Other way is casting the core panel with fresh GFRG monolithically. Other ways can also be implemented to check for better performance and maximum insulation.

4. Waste materials like rubber, leather, foam, etc. will be used in different proportions to fabricate samples of sandwich panels for tests.
5. Tests will be performed to determine the mechanical and insulation properties of the sample panels. Theoretical verification will be done wherever possible.
6. A provision for connecting the different units of panels will be made.
7. A manual to fabricate the designed sandwich panels will be produced.

In conclusion, the proposed work is expected to be completed within 2 to 3 years. In this time, insulating sandwich panels using waste generated in and around Agra from leather and footwear industries, etc, will be designed and fabricated. A prototype structure using these panels will also be constructed to demonstrate their effectiveness.

4. References

[1.] Howard Klee, "The Cement Sustainability Initiative", Volume 157 Issue 1, March 2004, pp. 9-11

[2.] Harika Chittella, Li Wan Yoon, Suganti Ramarad, Zee-Wei Lai, "Rubber waste management: review on methods, mechanism, and prospects", Polymer Degradation and Stability, vol 194, December 2021.

[3.] Trends in Solid Waste Management, The World Bank, 2021.

[4.] Annual Report 2019-20 on Implementation of Solid Waste Management Rules, 2016, Central Pollution Control Board, Delhi.

[5.] Asokan Pappu, Mohini Saxena, Shyam R. Asolekar, "Solid wastes generation in India and their recycling potential in building materials", Building and Environment, vol 42, Issue 6, June 2007, pp 2311-2320.

[6.] Jacob Coleman, Hans-Christian Wilhelm, "Concepts for a prefabricated wall panel to increase the uptake of straw and wool insulation in New Zealand", 54th International Conference of the Architectural Science Association 2020, pp 276–285.

[7.] Ravijanya Chippagiri, Hindavi R. Gavali, Rahul V. Ralegaonkar, Mike Riley, Andy Shaw, Ana Bras, "Application of Sustainable Prefabricated Wall Technology for Energy Efficient Social Housing", Infrastructure Resilience and Climate Action, Miguel Amado Sustainability, 2021.

[8.] Abdul Basir Awan, Faiz Uddin Ahmed Shaikh, "Compressive behavior of precast concrete sandwich panels containing recycled tyre crumb rubber core", Structural concrete journal of the fib, vol 23, Issue 5, October 2022, pp 2786-2802.

[9.] Kassahun G. Sellassie, Horace Keith Moo-Young Jr, Thomas B. Lloyd, "Determination of the thermal conductivity of shredded tyres by utilising a hot plate apparatus", Int. J. Environment and Waste Management, vol 1, May 2007, pp 179-191.

[10.] Benazzouk, O. Douzane, K. Mezreb, B. Laidoudi, M. Que´neudec, "Thermal conductivity of cement composites containing rubber waste particles: Experimental study and modelling", Construction and Building Materials, vol 22, April 2008, pp.573–579.

[11.] Gregory Woltman, Martin Noel, Amir Fam, "Experimental and numerical investigations of thermal properties of insulated concrete sandwich panels with fiberglass shear connectors", Energy and Buildings, vol 145, 15 June 2017, pp. 22-31.

[12.] A. Teklay, G. Gebeyehu, T. Getachew, T. Yaynshet, T. P. Sastry, "Preparation of value-added composite boards using finished leather waste and plant fibers", a waste utilization effort in Ethiopia, Clean Technologies and Environmental Policy, vol 19, 24 January 2017, pp 1285–1296.

[13.] M. Barbanera, E. Belloni, C. Buratti, G. Calabrò, M. Marconi, F. Merli, I. Armentano, "Recycled leather cutting waste-based boards: thermal, acoustic, hygrothermal and ignitability properties", Journal of Material Cycles and Waste Management, vol 22, 6 April 2020 pp 1339–1351.

[14.] Changhai Peng, Yail J.Kim, Junxue Zhang, "Thermal and energy characteristics of composite structural insulated panels consisting of glass fiber reinforced polymer and cementitious materials", Journal of Building Engineering, vol 43, November 2021.

[15.] H. Lakrafli, S. Tahiri, A. Albizane, M. Bouhria, M.E. El Otmani, "Experimental study of thermal conductivity of leather and carpentry wastes," Construction and Building Materials, vol 48, November 2013, pp 566-574.

[16.] Taher Abu-Lebdeh, Ashraf Fadiel, "Thermal conductivity of rubberized gypsum board", American Journal of Engineering and Applied Sciences, 2014, pp 12-22.s

[17.] Sara Gutiérrez González, Carlos Junco, Veronica Calderon, Ángel Rodríguez Saiz, Jesús Gadea, "Design and Manufacture of a Sustainable Lightweight Prefabricated Material Based on Gypsum Mortar with Semirigid Polyurethane Foam Waste", International Congress on Polymers in Concrete (ICPIC 2018), pp 449–455.

[18.] Muhammad Wasim, Osmar Oliveira, Tuan Duc Ngo, "Structural performance of prefabricated glass fibre concrete floor panel versus compressed fibre cement floor panel for an optimised volumetric module- A case study", Journal of Building Engineering, vol 48, 1 May 2022.

[19.] Thiago Moreira Flores, Thalis de Simas Koller, Sandro Heleno Auler, José de Souza, "Characterization of Animal Leather Dust Waste from the Footwear Industry", International Journal of Engineering and Science, vol 10, 8 August 2020, pp 27-31.

[20.] K. Ravichandran, N. Natchimuthu, "Natural Rubber - Leather Composites",

[21.] Ibrahim Almeshal, Bassam A. Tayeh, Rayed Alyousef, Hisham Alabduljabbar, Abdeliazim Mustafa Mohamed, Abdulaziz Alaskar, "Use of recycled plastic as fine aggregate in cementitious composites: A review", Construction and building materials, vol 253, 30 August 2020.

[22.] Meifeng He, Wenbin Hu, "A study on composite honeycomb sandwich panel structure", Materials and Design, vol 29, 2008, pp 709-713.

[23.] Md. R. Karim, Muhammad F.M. Zain, M.Jamil Fook C. Lai, Md. N. Islam, "Use of Wastes in Construction Industries as an Energy Saving Approach", Energy Procedia, vol 12, 2011, pp 915-919.

[24.] Sandesh Kiran.S, B. M Rajaprakash, "Standard Testing Methods for Natural Fiber based Hybrid Sandwich Composites", International Journal of Engineering Research & Technology (IJERT), vol 8 Issue 10, October-2019.

[25.] Mohd Faheem, Prof. Ateeque Ahmad, "Imprint and Status of Household Footwear Industry in Agra City of Uttar Pradesh: A General Review", International Journal of Trend in Scientific Research and Development (IJTSRD), vol 5 Issue 6, September-October 2021.