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Alternative Building Materials from Waste

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Abstract: *Globalization and urbanization growth are disbalancing the nature by creating technology and by increasing population respectively. Population growth is generating trash including the non-renewable ones. Use and throw objects came into existence and as a result, created wastes. After decades, the waste is generating beyond limits that it has created the mountain like piles in the landfills, which is creating hazards for the environment and human health. A better approach to reduce the waste is to recycle and reuse them as an alternative solution to building material industry. The question which arises here is that if wastes should be recycled or reused; what all are the waste materials which can be reused in building material industry without harming the environment. The recycling of waste materials produces lot of demerits to environment and human health. Polyethylene and rubber tires are being used in preparing the roads, plastic bottles are being used to build walls, fly ash is used in bricks etc. measures are being taken. The research paper will try to do a detailed SWOT analysis to find a suitable reusable waste material for building material industry, which will be environment friendly. The plastic waste, construction demolition waste and transport industry waste are the wastes that can be reused as building materials. The 3 wastes have the ability to withstand calamities and loads, are easy to build with, cheap, clean and has passed the structural tests. The paper intends to provide the information regarding the construction with the help of the 3 materials. This approach will help to manage the waste, build a sustainable environment, lower the greenhouse gases, maintain the natural resources etc.*

Key Word*:reusing, plastic waste; construction demolition waste; transportation industry waste; building materials.*

I. Introduction

In our life, death and waste are the two of the few things, that no one can change. However, with higher management, we will prepare ourselves. This right may be consummated by maintaining transparent and healthy surroundings. The environment can be maintained by reducing the waste generation, reducing the carbon footprint, low greenhouse gases emissions, low carbon emissions, reducing the use of natural resources etc. Through architecture, one can contribute to maintain the environment, by reusing the wastes in the building industry. The wastes which generates from various human activities, industries, factories, manufacturing plants, treatment plants etc. Different wastes generate, which is harmful for the environment and human health. Therefore, the paper will attempt to reuse the wastes in the product form (as per the specifications of government policies). The reusing of wastes will include cutting of waste into pieces, fibers, aggregates etc. Additionally, reusing of waste will be the replacement of conventional building materials with the new alternative material. The research paper will try to do a comparative analysis of various industrial wastes via SWOT analysis to find the suitable waste material for construction. The research will bring ecological, economic and environmental benefits in waste material management and building material industry. The construction of buildings using the alternative building material from waste will give the approach to sustainable buildings.The research paper aims to do a comparative analysis of various industrial waste materials to find out suitable waste material for construction and to provide construction information to construct a building from the suitable waste construction material.

II. Material and Methods

In the building material industry, there are various kinds of wastes, which are used and can be distinguished as follows:

Result squanders is that squander which is created by enterprises and incorporates any material which is viewed as useless during any assembling procedure from factories, plants and mines. By and large, they are dumped in landfills. A portion of the instances of mechanical squanders are – Silica seethe, Slag, Sludge, Fly debris, Sandpaper, Metals, Glass etc. [4]

2.1 Study Duration: January 2020 to June 2020.
2.2 Sample size: 8 waste materials are taken into consideration for the research study.
2.3 Sample size calculation: The sample size is analyzed in the form of SWOT analysis and then case studies are done to understand the application of the resultant waste materials from the SWOT analysis. The SWOT analysis is done on the basis of following parameters-

1. Ease of workability
2. Impact of behavior with raw waste material
3. Recycling and reusing technique
4. Alternative uses
5. Fire resistance
6. Impact over the environment and health

The case studies that are taken for the study are as follows-

1. Eco-ark, Taiwan
2. House by Ingrid, Caribbean
3. Bottle school by Hug it forward, Quisaya, Guatemala
4. Farm house, Nigeria
5. Manav sadhana activity center, Ahmedabad

2.4 Subjects & selection method: The parameters for SWOT analysis are selected as, to built any structure, materials are studied on the basis of parameters like Ease of workability, Impact of behavior with raw waste material, Recycling and reusing technique, Alternative uses, Fire resistance and Impact over the environment and health. While, case studies are selected as all the projects are built out of the resultant waste material from SWOT analysis, constructed out of plastic bottles as brick for the structure, concrete as a binding material, ballast and aggregates as filler material for plastic bottles and are constructed for more than one story.

2.5 Inclusion criteria:

1. It includes the construction of elements by taking the recycled product as the base product with other conventional materials.
2. It includes the construction of expos, residences, farm houses, temporary pavilions, exhibition and art galleries, restaurants, cafes, schools, offices etc.
3. It will provide ways of reusing waste in building material industry and will help in reducing wastes.

2.6 Exclusion criteria:

1. Recycle and Reuse of wastes is limited to local level and factory level.
2. The paper will just give the idea for the use and application of new solutions as an alternative building material from waste materials.

2.7 Procedure methodology

- List down the various types of wastes.
- Categorizing wastes which can be used in building material industry.
- Analyzing the categorized wastes.
- Study the research papers related to recycling and reusing of the waste.
- To do the SWOT analysis of different waste materials, to find out suitable waste material for construction.
- To do the case studies of the buildings constructed from the waste materials, to collect construction information.

The waste materials are categorized as biodegradable and non-biodegradable. After that industrial wastes are selected from the classified wastes. The reason for choosing some of the waste materials for the analysis is due to their significance, availability, alternative use in building industry, generation of waste, advantages, impact over environment etc. the selected waste materials are silica fumes, slag, sludge, organic waste, construction and demolition waste, transportation industry waste and plastic waste. All the mentioned waste materials are combined in a table to gather their basic detailed information.The parameters which are going to be mentioned in the table for waste materials are as follows:

1. Category of waste: to which family the waste belongs to

2. Waste product: name of the waste product
3. Origin of waste**:** from where the waste product generated
4. Amount or percentage of waste generation**:** total waste generation in a month or year
5. Behavior with the waste product**:** the form in which waste product gets collected and supplied
6. Alternative use of waste product**:** uses of waste product other than usual use
7. Reason of using waste product**:** why the waste product is getting employed to generate new things, what are its characteristics and properties etc.
8. Recycling or reusing technique**:** how the waste product is getting recycled or reused for the new product
9. Life time of alternative product**:** how long the new alternative material will stay
10. Advantage of alternative product**:** what are the merits that an alternative material will provide
11. Disadvantage of alternative product**:** what are the demerits that an alternative material will lag in
12. Impact over environment and health**:** what will be the effects over the health and environment after a

CATEGORY OF WASTE	WASTE PRODUCT	ORIGIN OF WASTE	AMOUNT OR PERCENTAGE OF GENERATION	BEHAVIOUR WITH THE WASTE PRODUCT	ALTERNATIVE USE OF WASTE PRODUCT	REASON OF USING WASTE PRODUCT	RECYCLING OR REUSING TECHNIQUE	LIFE TIME OF ALTERNATE PRODUCT	ADVANTAGE OF ALTERNATIVE PRODUCT	DISADVANTAGE OF ALTERNATIVE PRODUCT	IMPACT OVER ENVIRONMENT AND HEALTH
NON - HAZARDOUS WASTE	SILICA FUME	fine powder obtained from ferrosilicon industry	exceeds 1 million tonnes per annum	delivery in form of- 1. as-produced (fine powder)	1. used to construct a New TJ ORN Bridge in sweeden	fine particles can fill up the spaces in concrete mix	fine powder or slurry is reused directly in place of polymers	20% strength can be increased with 10 % dose of silica fume	1. elements with high strength concrete under loading is improved.	1. self contraction	1. because it is an amorphous form of silica, silica fume is not associated with severe health concerns such as silicosis.
				2. compacted (tumbling the silica-fume particles in a silo)	2. Girders				2. resistance capacity is higher	2. the construction is difficult	2. can cause pollution
				3. slurried (+water)	3. in high rise structures to increase the life time of the structure without any affects				3. sizes of structural elements are reduced.	3. surface crack caused by wet expansion	
				4. pelletized (water + cement)	4.in important structures which had a high strength when compared with another						
					5. mineral admixture in concrete						

Figure 1. detailed information of silica fume

long use or over a period of time.

CATEGORY OF WASTE	WASTE PRODUCT	ORIGIN OF WASTE	AMOUNT OR PERCENTAGE OF GENERATION	BEHAVIOUR WITH THE WASTE PRODUCT	ALTERNATIVE USE OF WASTE PRODUCT	REASON OF USING WASTE PRODUCT	RECYCLING OR REUSING TECHNIQUE	LIFE TIME OF ALTERNATE PRODUCT	ADVANTAGE OF ALTERNATIVE PRODUCT	DISADVANTAGE OF ALTERNATIVE PRODUCT	IMPACT OVER ENVIRONMENT AND HEALTH
NON - HAZARDOUS WASTE	SLAG	co - product of steel and iron production	14 million metric tons (US)	1. Air-Cooled Blast Furnace Slag	1. preparing composite cement	1. less carbon dioxide emmission during production	1. 90 percent is ACBFS		1. improves flexural strength		
				2. Expanded or Foamed Blast Furnace Slag	2. aggregates in preparing concrete	2. lower hydration heat during hardening	2. production of expanded blast furnace slag is no longer favored		2. improves compressive strength		
				3. Pelletized Blast Furnace Slag	3. used in agriculture, for treatment of soil improvement	3. lower permeability			3. better workability		
				4. Granulated Blast Furnace Slag	4. roads, highways, pavements, bridges, marine constructions, hydraulic dams etc.	4. good resistance to sulphate attack			4. structure of hardened concrete is more compact		
				5. less than 10 percent of the blast furnace slag generated is disposed of in landfills.	5. insulation wool as slag wool				5. long term strengths		

Figure 2. detailed information of slag

CATEGORY OF WASTE	WASTE PRODUCT	ORIGIN OF WASTE	AMOUNT OR PERCENTAGE OF GENERATION	BEHAVIOUR WITH THE WASTE PRODUCT	ALTERNATIVE USE OF WASTE PRODUCT	REASON OF USING WASTE PRODUCT	RECYCLING OR REUSING TECHNIQUE	LIFE TIME OF ALTERNATE PRODUCT	ADVANTAGE OF ALTERNATIVE PRODUCT	DISADVANTAGE OF ALTERNATIVE PRODUCT	IMPACT OVER ENVIRONMENT AND HEALTH
	SLUDGE	1. settles suspension from conventional drinking water treatment		1. classification	1. as filling material in concrete production	1. improved compressive strength	1. in form of powder		1. Energy Generation	1. Impacts Air Quality	Only some impacts from air emissions
		2. as a by-product from steel industry		2. magnetic separation	2. as replacement of fine aggregate in asphalt paving	2. freeze-thaw resistance	2. in form of aggregate		2. Control the Spread of Diseases	2. Release of Dioxins	other impacts, such as emissions to water and soil impacts could not be quantified.
				3. leaching	3. replacement of sand for concrete in masonry construction	3. waterproofness			3. Recovery of Precious Metals	3. Mercury Contamination	
				4. roasting							

Figure 2. detailed information of sludge

CATEGORY OF WASTE	WASTE PRODUCT	ORIGIN OF WASTE	AMOUNT OR PERCENTAGE OF GENERATION	BEHAVIOUR WITH THE WASTE PRODUCT	ALTERNATIVE USE OF WASTE PRODUCT	REASON OF USING WASTE PRODUCT	RECYCLING OR REUSING TECHNIQUE	LIFE TIME OF ALTERNATE PRODUCT	ADVANTAGE OF ALTERNATIVE PRODUCT	DISADVANTAGE OF ALTERNATIVE PRODUCT	IMPACT OVER ENVIRONMENT AND HEALTH
	FLY ASH	1. residue from power plants		1. incineration	1. calcium sulphoaluminate cement	1. effectiveness in volume reduction	in form of fine fly ash residue		1. reduce concrete dosage	1. leads to low rate of gain of early strength as compared to mix only with cement.	1. contaminate drinking water supplies
		2. solid waste incineration technology			2. cement and concrete manufacturing	2. weight reduction			2. improve concrete mechanical strength	2. Stripping time of formwork increases due to late setting of cement as compared to mix only with cement.	2. damage vital human organs and nervous system
					3. bricks, pavements	3. toxicity reduction			3. improves concrete durability resistance		3. air and water pollution on large scale
					4. lightweight aggregates	4. energy and resource conservation			4. reduce bleeding		4. hazard to underground water quality
									5. reduce cracking		
									6. decrease heat during hardening of concrete		

Figure 1. detailed information of fly ash

CATEGORY OF WASTE	WASTE PRODUCT	ORIGIN OF WASTE	AMOUNT OR PERCENTAGE OF GENERATION	BEHAVIOUR WITH THE WASTE PRODUCT	ALTERNATIVE USE OF WASTE PRODUCT	REASON OF USING WASTE PRODUCT	RECYCLING OR REUSING TECHNIQUE	LIFE TIME OF ALTERNATE PRODUCT	ADVANTAGE OF ALTERNATIVE PRODUCT	DISADVANTAGE OF ALTERNATIVE PRODUCT	IMPACT OVER ENVIRONMENT AND HEALTH
BIODEGRADABLE WASTE	ORGANIC WASTE	found in municipal solid waste		1. compost	1. portland cement concrete	powder has very fine particles that it can be used as replacement of sand particles in cement and other products	1. fermentation		1. provides high resistance to brick clays when ashes are replaced by sand	1. higher water absorbtion charachteristics influences reduction in workability	1. produces air pollution
		food, paper, manure, sewage, banana leaves etc.		2. landfill	2. ceramic products tiles, brick blocks, pavements etc.		2. burning with high temperature		2. provide tough materials with the addition of rubber powder	2. high sulphur content influences compressive strength	2. under earth water pollution
				3. incineration	3. interior partitions, furniture, acoustic absorption and thermal insulation		3. microbes decomposition			3. can't provide tough materials	3. salt in organic wastegenerate dioxin after burning
				4. fast fermentation			4. anaerobic bacteria decompose			4. loss of carbon emission	
				5. biogas							

Figure 3. detailed information of organic waste

CATEGORY OF WASTE	WASTE PRODUCT	ORIGIN OF WASTE	AMOUNT OR PERCENTAGE OF GENERATION	BEHAVIOUR WITH THE WASTE PRODUCT	ALTERNATIVE USE OF WASTE PRODUCT	REASON OF USING WASTE PRODUCT	RECYCLING OR REUSING TECHNIQUE	LIFE TIME OF ALTERNATE PRODUCT	ADVANTAGE OF ALTERNATIVE PRODUCT	DISADVANTAGE OF ALTERNATIVE PRODUCT	IMPACT OVER ENVIRONMENT AND HEALTH
HAZARDOUS WASTE	TRANSPORTATION INDUSTRY WASTE	1. freight transport, hicle maintenance and cleaning, freight handling and warehousing operations.		1. in natural form	1. for fixing and sealing soils in agricultural domain	great resistance to temperature variations	as a lightweight filling material for soil reinforcement		increases the capacity to absorb energy from impacts	concrete with used tyre presented a decrease in mechanical properties	1. hazard fire which is almost impossible to extinguish
		2. repair and servicing of vehicles		2. cut in aggregates	2. in hydraulic domain (retaining walls, breakwaters)	reduced noise	as replacement of sand in glass fibre reinforced composite		reduce damage from collisions	contaminate groundwater	Landfills can also emit harmful gases into the atmosphere
				3. in powder form	3. light concrete	lower maintenance cost	as filler or replcement of fine aggregates in concrete		increase deformability and ductility of concrete		
					4. pavements for roads						

Figure 6. detailed information of transportation industry waste

CATEGORY OF WASTE	WASTE PRODUCT	ORIGIN OF WASTE	AMOUNT OR PERCENTAGE OF GENERATION	BEHAVIOUR WITH THE WASTE PRODUCT	ALTERNATIVE USE OF WASTE PRODUCT	REASON OF USING WASTE PRODUCT	RECYCLING OR REUSING TECHNIQUE	LIFE TIME OF ALTERNATE PRODUCT	ADVANTAGE OF ALTERNATIVE PRODUCT	DISADVANTAGE OF ALTERNATIVE PRODUCT	IMPACT OVER ENVIRONMENT AND HEALTH
INERT AND NON-BIODEGRADABLE WASTE	CONSTRUCTION DEMOLITION WASTE	from structures that detoriorate in 10 to 20 years	10-20 % of the municipal solid waste (excluding large construction projects)	1. sorting	concrete with wood waste is of low strength	do not cause odour or pollution	bricks, wood, metal, titles are recycled		does not create chemical or biochemical pollution	consuming enormous quantities of stone, sand and drinking water	chokes surface drains
			10-12 million tons of waste annually	2. crushing	concrete with polystyrene can be used to obtain prefabricated units	transportation cost is also reduced	Recycling of concrete and masonry waste done abroad like U.K., U.S.A. etc.		Uses Less Energy	consume huge quantities of cement	fine particles of dust cause air pollution in the region
				3. sieving			concrete from demolition can be used as an aggregate			cause obstruction to traffic	
							as filler or replcement of fine aggregates in concrete				

Figure 4. detailed information of construction demolition waste

CATEGORY OF WASTE	WASTE PRODUCT	ORIGIN OF WASTE	AMOUNT OR PERCENTAGE OF GENERATION	BEHAVIOUR WITH THE WASTE PRODUCT	ALTERNATIVE USE OF WASTE PRODUCT	REASON OF USING WASTE PRODUCT	RECYCLING OR REUSING TECHNIQUE	LIFE TIME OF ALTERNATE PRODUCT	ADVANTAGE OF ALTERNATIVE PRODUCT	DISADVANTAGE OF ALTERNATIVE PRODUCT	IMPACT OVER ENVIRONMENT AND HEALTH
NON-BIODEGRADABLE WASTE	PLASTICS	municipal solid waste	5.47 lakh tonnes in uttar pradesh	1. burning	1. bricks	1. lightweight	1. mechanical recycling	300 - 500 years	1. reduces water pollution	1. VOCs (volatile organic compounds) released from plastic recycling harm the environment	heart diseases, asthma, nausea
				2. incomplete combustion	2. concrete aggregate	2. strong	2. chemical recycling		2. conserves natural resources	2. generates carbon emissions	lungs damage, neurological problems etc.
				3. transforming into fibres	3. fibre reinforcement in structural concrete	3. clear	3. energy recovery			3. does not guarantee good quality products	
						4. longer life span				4. increase low quality jobs, These include sorting the garbage, cleaning toxins and doing the other manual and the intensive labor	
						5. easy to recycle or reuse					

Figure 8. detailed information of plastic waste

As a result, from the above table, the waste materials are mostly used for-

- the improvement of concrete and its production and
- as the alternative material in bricks, tiles, pavements etc.

2.8 SWOT analysis

SWOT analysis is done to evaluate any product, material etc. so the basis of some parameters according to the function and purpose of the product or material. So, evaluating the waste materials to obtain the suitable one for the building material industry will be done with the help of SWOT analysis only.

The SWOT analysis will be done on 8 selected waste materials, which are- Silica fume, slag, sludge, fly ash, organic waste, construction demolition waste, transportation industry waste and plastic waste; on the basis of following parameters (deduced from the literature study):

1. ease of workability
2. impact of behavior with raw waste material
3. recycling and reusing technique
4. alternative uses
5. fire resistance
6. impact over environment and health

2.8.1 On the basis of ease of workability

First parameter of SWOT analysis is about workability. Ease of workability for the waste materials here is related to the handling of the raw waste material, and the person who is related to that specific work. Among all the wastes, the plastic waste is easy to work from waste collection stage to sorting stage. Labor can easily work with the plastic waste and it produces less odour which is bearable.

Silica fume, slag and fly ash cannot be collected and sorted out by labor; these wastes need factory for such kind of work, and also, the fine particles produce air pollution and problems to human beings.

ON THE BASIS OF EASE OF WORKABILITY				
WASTE	**STRENGTH**	**WEAKNESS**	**OPPORTUNITY**	**THREATS**
SILICA FUME	used in any form like- fine powder, densified, slurried and pelletized	particles and fine powder are difficult to collect by hand	labour is needed to convert the raw waste into useful form, hence improves employment problem	units to treat raw waste need to be built near manufacturing units
SLAG	various forms to be used easily- Air-Cooled Blast Furnace Slag, Expanded or Foamed Blast Furnace Slag, Pelletized Blast Furnace Slag, Granulated Blast Furnace Slag	difficult to collect by hand and shovel etc.	labour is needed to run the units, hence improves employment problem	units to treat raw waste need to be built near manufacturing units
SLUDGE	sorting by- classification, magnetic separation, leaching, roasting helps in using the useful elements for a specific purpose	difficult for labour to work due to severe bad odour and presence of bacteria and germs	labour is needed to run the units, hence improves employment problem	units to treat raw waste need to be built near manufacturing units
FLY ASH	fine powder of ashes has a good use in concrete mixture which can improve its mechnical strength	ashes are difficult to collect by hand	incineration helps in using fly ash to obtain different purposes	labour cost is very low and working with fly ashes cause breathing problems to labours
ORGANIC WASTE	–	difficult for labour to work due to severe bad odour and presence of unidentifiable objects	–	labour cost is low and disposing off is finding no land
CONSTRUCTION DEMOLITION WASTE	–	labour is required to take off the waste from site to treatment zone	poor labour got employment though they are paid less	labour got affected with breathing problems due to dust particles in air
TRANSPORTATION INDUSTRY WASTE	easy to handle and maintain	need to be away from any fire prone zone	–	land for diosposal is getting vulnerable
PLASTIC WASTE	is widely used for storage, serving etc.	need to be away from any fire prone zone	labour required for collection and sorting	land for diosposal is getting vulnerable

Figure 5. SWOT analysis on ease of workability

2.8.2 On the basis of impact of behavior with raw waste material

Second parameter helps in understanding the way in which raw waste material get treated. When the raw waste materials get collected and sorted out, what is the first thing that happens with the waste as stage 1 in recycling process.

ON THE BASIS OF IMPACT OF BEHAVIOUR WITH RAW WASTE MATERIAL				
WASTE PRODUCT	**STRENGTH**	**WEAKNESS**	**OPPORTUNITY**	**THREATS**
SILICA FUME	can be converted and used into any form like- fine powder, densified, slurried and pelletized	raw form can not be used directly, has to be mixed or added with some main components	utilisation of waste materials for converting them into building materials will result in bringing down the building material cost, and therefore, lead to conservation of natural resources like clay and sand.	steel manufacturing plants need captive power generation to work, which can affect the generation of silica fume waste
SLAG	converted into various forms to be used easily- Air-Cooled Blast Furnace Slag, Expanded or Foamed Blast Furnace Slag, Pelletized Blast Furnace Slag, Granulated Blast Furnace Slag	direct use of raw form can cause land pollution, deteriorate soil conditions	raw material and manpower resources may potentially increase the production of iron and steel industries and hence the slag production	labour productivity, technological development, managerial competence, research and development etc. will lead to loss in iron and steel industries, hence loss in slag production
SLUDGE	helps in recovery of precious metals for ex- gold and silver	raw waste sludge has slurry texture with a bad odour that no one can use it directly	treated sludge can be used in producing bricks, concrete, as an aggregate in asphalt pvements etc.	waste sludge has to be sorted by- classification, magnetic separation, leaching, roasting; which can be done by machinery but at the initial stage, it requires manpower to get collected and sorted
FLY ASH	using fly ashes, can help in energy and resource conservation	ashes create air and water pollution on large scale	if treated properly, can be used to produce cement, brick pavements etc.	production of ashes from coal is large and is a big problem to store it
ORGANIC WASTE	is biodegradable in nature	coarse aggregate texture with a bad odour that no one can use it directly	has many applications other than construction industry	though is biodegradable in nature but, large quantities of waste is difficult to dispose off and take lot of time to get decompose
TRANSPORTATION INDUSTRY WASTE	has lower maintenance cost	can catch fire easily which will be very hard to extinguish	can be used to pave roads and act as aggregate for concrete	sizes and quantity of waste is large and is not easy to find land to dispose off
CONSTRUCTION DEMOLITION WASTE	recovery of metals, woods, and other objects can help in creating other recycling projects	there is no reserved land for the demolition waste which chokes drains and roads	-	uses manpower to get sorted and also the labour cost is very low
PLASTIC WASTE	is a sustainable product hence the lifetime is about 300 years	can catch fire easily which will be very hard to extinguish	provides variety of options to be used for producing objects	disposing of waste in landfills is a greta danger to environment and its habitants

Figure 6. SWOT analysis on impact of behaviour with raw waste material

From the above table, it can be analyzed that, all the wastes have to go through recycling process and the waste materials which got additional properties to be used again are silica fume, sludge, organic waste and transportation industry waste. These wastes after getting treated, are useful to be used again, they did not lose their properties while they get additional ones. Apart from these wastes, slag, fly ash, construction demolition waste and plastic waste get deteriorated in their quality and properties.

2.8.3 On the basis of recycling and reusing technique

Third parameter focuses on the usefulness of recycling, impact of recycling and its future.

ON THE BASIS OF RECYCLING AND REUSING TECHNIQUE				
WASTE PRODUCT	**STRENGTH**	**WEAKNESS**	**OPPORTUNITY**	**THREATS**
SILICA FUME	in form of fine powder or slurry is reused directly in place of polymers	fine powder creates pollution	helps in conserving natural resources	has impact over environment
SLAG	aggregates in preparing concrete, roads, pavements, marine construction, hydraulic dams etc.	government is no longer in favour	helps in conserving natural resources	–
SLUDGE	in form of powder and aggregate in concrete mixture and bricks	releases dioxins	helps in conserving water and land from contamination	has impact over human health
FLY ASH	in form of fine fly ash residue in cement, bricks, pavements etc.	releases toxic gases	helps in conserving natural resources	has impact over environment
ORGANIC WASTE	fermentation, burning with high temperature, microbes' decomposition, anaerobic bacteria decompose are the recycling processes	–	provides with more land to be used for other purposes	recycling produces air pollution and under water pollution
TRANSPORTATION INDUSTRY WASTE	as a lightweight filling material for soil reinforcement, concrete, glass fibre reinforced composite	recycling units need to be away from city zone due to air and water pollution	helps in reduction of resource and energy loss	recycling produces air pollution and water pollution
CONSTRUCTION DEMOLITION WASTE	as filler or replacement of fine aggregates in concrete	recycling units do not have enough strength to provide for further use	helps in reduction of resource and energy loss	–
PLASTIC WASTE	mechanical recycling, chemical recycling, energy recovery are the recycling processes	requires factory units to recycle and supportive power generation	helps in reduction of resource and energy loss	recycling produces air pollution and water pollution and causes severe respiratory problems

Figure 7. SWOT analysis on recycling and reusing technique

From the above table, it can be analyzed that, after recycling the waste materials, they get transformed into useful materials and can be used to produce new materials or can be added with other materials to improve their properties. However, the impact of recycling over the environment and human health is not very satisfying.

2.8.4 On the basis of alternative uses

Fourth parameter focuses over the alternative uses of waste materials in building material industry.

It can be analyzed that, silica fume, slag, sludge, fly ash and construction demolition waste has very limited alternative uses, for ex- these wastes can be used as an admixture, as a filler, as a fine aggregate and coarse aggregate, as a replacement in concrete and cement mixtures effectively. Their uses in other building materials is not very effective due to their properties. While, organic waste, transportation industry waste and plastics waste have wide range of alternative uses, for ex- as an aggregate, as an admixture, as a filler material, as fibers, direct form etc. can be used in bricks, tiles, pavements, in concrete, for soil improvement etc. these wastes can be directly used to create facades, partitions, for acoustical purposes etc.

ON THE BASIS OF ALTERNATIVE USES				
WASTE PRODUCT	**STRENGTH**	**WEAKNESS**	**OPPORTUNITY**	**THREATS**
SILICA FUME	in form of fine powder or slurry is reused directly in place of polymers	problem of self contraction happens	sizes of structural components are reduced and has higher resistance capacity	surface crack caused by wet expansion
SLAG	aggregates in preparing concrete, roads, pavements, marine construction, hydraulic dams etc.	–	improves flexural and compressive strength	–
SLUDGE	in form of powder and aggregate in concrete mixture and bricks	no major impact over the properties of concrete	control the spread of diseases	works as a replacement of sand and aggregates in bricks and concrete
FLY ASH	in form of fine fly ash residue in cement, bricks, pavements etc.	Stripping time of formwork increases due to late setting of cement as compared to mix only with cement.	reduces cracking, improves durability	leads to low rate of gain of early strength as compared to mix only with cement
ORGANIC WASTE	fermentation, burning with high temperature, microbes' decomposition, anaerobic bacteria decompose are the recycling processes	do not provide tough materials	provides high resistance to brick clays when ashes are replaced by sand	higher water absorbtion charachteristics influences reduction in workability
TRANSPORTATION INDUSTRY WASTE	as a lightweight filling material for soil reinforcement, concrete, glass fibre reinforced composite	concrete with used tyre presented a decrease in mechanical properties	increases the capacity to absorb energy from impacts	can't be used in residences, power generation plants, thermal power plants
CONSTRUCTION DEMOLITION WASTE	as filler or replacement of fine aggregates in concrete	consume huge quantities of cement	can be used effectively as filler; as it can provide better resistance to shocks and transfer loads	do not provide enough strength and properties for a long use
PLASTIC WASTE	mechanical recycling, chemical recycling, energy recovery are the recycling processes	increase low quality jobs, These include sorting the garbage, cleaning toxins and doing the other manual and the intensive labor	provides wider range of uses of recycled plastics like tiles, bricks, flooring, cement aggregates, fibre glass etc.	does not guarantee good quality products

Figure 8. SWOT analysis on alternative uses

2.8.5 On the basis of fire resistance

Fifth parameters help in stating if the recycled waste material is fire resistant or not. It helps in analyzing the use of recycled waste material in fire prone areas i.e. which material is suitable to be used and

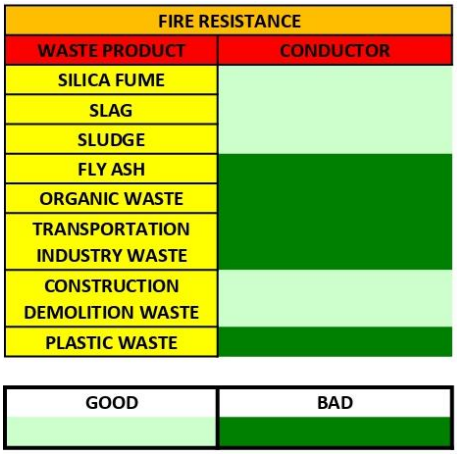

Figure 9. SWOT analysis on fire resistance

which one to be not used.

2.8.6 On the basis of impact over environment and health

Sixth parameter helps in evaluating that on recycling and reusing the recycled waste material, which material is deteriorating the environment and human health mostly.

So, from the table it is clear that fly ash, transportation industry waste and plastic waste has non-bearable impact over the environment and human health and it cannot be negotiated.

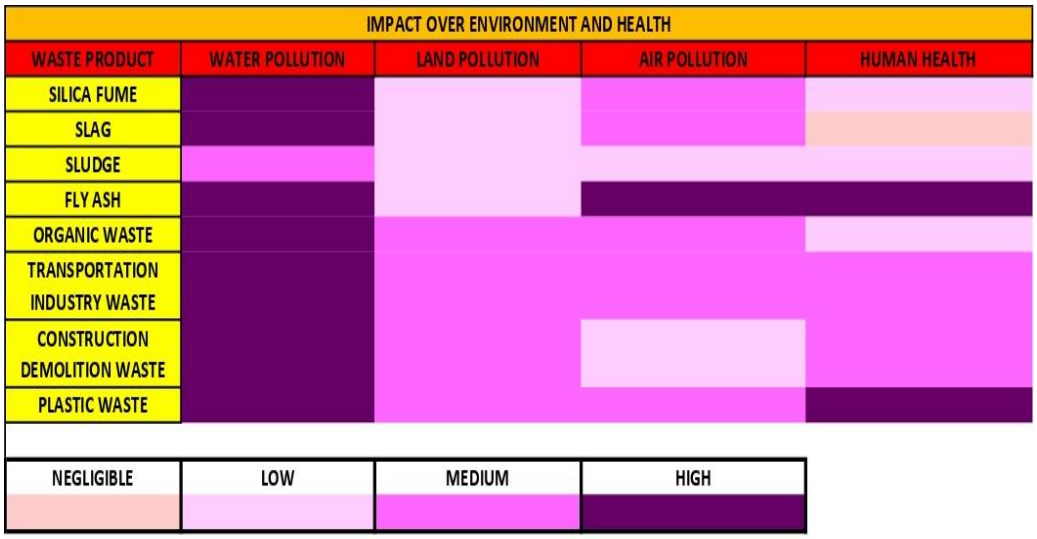

Figure 10. SWOT analysis on impact on environment and health

2.8.7 Observations from SWOT analysis

From the overall SWOT analysis, it is observed that-

Silica fume is not easy to work manually, but provides better alternative use in concrete, creates less environment pollution and useful recycled products.

Slag is not easy to work manually, gives recuperation of valuable metals from the waste aggregates, has limited alternative uses, creates less environmental pollution.

Sludge is not bearable by any human being to work on, but recycling provides valuable alternative product to use with other materials, creates less environmental pollution.

Fly ash is already a burnt product from coal mines, has very fine powder texture, which cannot be handled by bare hands, has limited alternative uses, catches fire easily and is a severe environment and health hazard component.

Organic waste requires mechanical equipment to be work upon for collection and sorting, creates less pollution, many alternative uses in architectural and other fields, but provides less durability, strength etc.

Construction demolition waste requires mechanical equipment to get collected and sorted, provides recovery of resources like wood, metals (gold, silver, copper etc.), plastics etc. which can be recycled to produce other useful products, but creates air and water pollution which is not beneficial for environment and human health, fails in providing enough strength and durability needs as the waste is obtained from a fallen out structure.

Transportation industry waste are metal parts, rubber tires, wires, plastics, leather etc. need to be sorted out mechanically, as they cannot be handled by any human being; on recycling, it produces extreme toxic gases which causes air pollution and respiratory problems; this waste provides many alternative uses with less negative future impacts; has bad resistance to fire, hazard fire will be impossible to extinguish.

Plastic waste is the most growing waste in the world, and can be collected and sorted with the help of human labor (poor ragpickers get employed though they are paid less), recycling (burning) creates air pollution and releases toxic gases, which affects environment and health also, sensitive to fire, future of recycled plastic waste do not create unbearable effects over environment and health till the plastic come into contact of fire, plastic can be used after recycling and without recycling which is favorable position of plastic waste for example reusing is possible; reusing don't decays the quality.

Figure 11. observation of SWOT analysis

2.8.8 Inferences from SWOT analysis

Because of globalization, there is an extreme increment in the waste generation. These wastes can be recycled or reused with proper research and development, technology, awareness and support. Recycling in factories requires burning and melting of the many wastes, which is a serious problem towards environment and health issues. Though it is acceptable that recycling of wastes provides better properties and qualities so that the waste material can be used again, but saving environment is also important. Wastes like silica fume, slag, sludge, fly ash needed to be recycled before reusing them. Direct use of these wastes does not provide beneficial results.While wastes like construction demolition wastes, transportation industry wastes and plastic wastes can be used directly. Recycling of these wastes is a hazard for atmosphere, also reduces the quality of the waste material. The three wastes mention later has many alternative uses when reused.

Construction demolition waste specifically concrete and bricks, can be used directly in filling the foundation excavation, solid bricks can be used as non-structural constructions like partitions, playground furniture etc.; collected wood and wood objects from demolished site can be reused as wood dust, as fibers by converting them into pieces or particles for manufacturing of particle and fiber boards, as a filler material in thermal walls, as acoustical panels etc.; metals from electrical appliances can be recovered and melted to get wires again; metal window and door frames can be recycled into liquid metal and reused again in the form of raw metal, as metal is considered as worthless when it get rusted and burnt out completely. Hence, there are many alternative uses of construction demolition waste in building material industry.

Transportation industry waste consists of waste vehicular tires, metal bodies etc. of vehicles. Among all the parts of a vehicle, rubber tires are recycled and reused to use as an alternative in building material industry. Recycling of rubber tires includes burning and melting, which releases extreme harmful toxic gases which is very harmful for environment and human health, that's why it is effective if rubber tires will be reused in the structure of fine and coarse aggregates in the laying of road, bricks, pavements, etc. can be used directly for the soil embankment by stacking rubber tires.

Plastic waste is considered sustainable because it takes almost 300 to 500 years to decompose, hence can be reused for construction of structures which is away from fire prone zone. Plastic bottles can be reused in the form of bottle bricks to construct walls, piers, plinths etc. bottle brick is a reusing technique in which plastic bottles are filled with sand and other fine and coarse aggregates. Plastic waste can be transformed into fibers and added with cement mix to create bricks; can be converted into small pieces to act as coarse aggregate in concrete mix. Reusing plastic waste do not create any environmental and health related issues. It is easily obtainable and easy to work with material. No skilled labor needed to work with plastic waste.

Therefore, from the SWOT analysis' inferences, the materials which can be reused as an alternative building material got selected which are- plastic waste, construction demolition waste and transportation industry waste. But to construct a structure, technical information should be provided on how much strength the material will provide, strength of individual unit, load bearing capacity, number of floors that are allowed to be built, benefits, structural or aesthetical etc. So, to find out the technical data, analysis of case studies is going to be done, to understand the construction and other technical information about the waste material used. In the following chapter, case studies are going to be done and the criteria of their selection will be explained.'

2.9 Case studies

For case studies, examples will be taken which are built out of plastic waste, transportation industry waste and construction demolition waste. There are many structures which are built out of PET plastic bottles in India and Abroad. William F. Peck constructed house in 1902 in Tonopah, Nevada [3]. 10,000 beer bottles were used to construct the house, but the house get demolished in 1980s. Around 1905, a house used 51,000 beer bottles by Tom Kelley in Rhyolite, Nevada. Ecological house constructed with 8,000 bottles in 2002; diamond school in 2004; reserve water tank at san martin, Honduras in 2005; sky field house in Honduras in 2005; retirement home constructed by 13,500 plastic bottles in Serbia in 2006; house constructed from 4,000 mud filled plastic bottles in Hyderabad, 2007; park of life foundation using plastic bottles in Columbia, 2008; houses in Nigeria and Uganda around 2010; 1.8 million plastic bottles used to construct expo pavilion of Taiwan in 2010; in May 2011, Samarpan foundation constructed schools in New Delhi etc. [8]are few projects showing the timeline of reusing the plastic waste and other construction and demolition wastes as an alternative building material.

The projects mentioned above are small scale, and are constructed with more techniques and materials. Projects like- Eco-Ark in Taiwan, house by Ingrid, bottle school by Hug It Forward, farm house at Nigeria and Manav sadhana in Ahmedabad are constructed out of plastic bottles, concrete, cement, sand, rubber tires etc. with 2 and more story floors.

The case studies are selected by considering the 3 waste materials (plastic waste, transportation industry waste and construction demolition waste). Eco-Ark in Taiwan, house by Ingrid, bottle school by Hug It Forward, farm house at Nigeria and Manav sadhana in Ahmedabad projects are selected for case studies. The projects are constructed out of plastic bottles as brick for the structure, concrete as a binding material, ballast and aggregates as filler material for plastic bottles and are constructed for more than one story. Site area of projects is varying and the requirements of each project are different. These projects are selected and are going to be analyzed on the basis of parameters which are found out from literature study.

All the parameters of analysis are going to be analyzed for elements of space making (as the elements are composed to form a unified building), for all the projects:

1. Material – material of the element
2. Lifetime – duration till the material exist
3. Span – maximum length of walls, span of openings and doors, partitions
4. Height / No. of floors – height of columns, walls, partitions, openings, parapet
5. Aesthetics / structural – purpose of the element in the project
6. Load bearing / non-load bearing – whether the element in the project is taking any load or not
7. Strength and lifetime are other two parameters which are going to be provided for the individual unit of bottle brick.
8. Type of bond – bonding used in the bricks to construct walls, partitions, floors, columns
9. Topography – type of terrain over which the project is built
10. No. of story – total no. of floors in the respective project

2.9.1 Eco-ark, Taiwan

The project is chosen as the protagonist building material is recycled PET plastic bottles, fixed over steel frame skeleton and achieved nine story height. The project is world's largest building fabricated out of waste. The project was able to withstand the harsh climate and calamities of the country. After the event, the building got dismantled to install it in other cities.

The Eco Ark is an expo building designed to stage fashion shows and as an international floral exhibition, starts in November. It was designed to accommodate around 2,000 visitors during the event. The building used 1.5 million recycled plastic bottles to construct the façade, partitions, lighting fixtures. The building would get dismantled to be built in other locations therefore, the plastic bottle is divided into panels of 3.2 sq. m. and the whole structure was created by steel frame skeleton to place the panels. [2]

The major challenge in front of the architects was the climatic conditions and hazards of Taiwan. Floods, earthquakes, fires, wind storms, strong prevailing winds etc. needed to be considered to make the structure stand during these conditions. The team coated the exterior of the building with a fireproof laminate. This makes the building more fire proof as high-grade PET is already less flammable than wood. And if the polli bricks get filled with water, it increases the time of fireproofing by 2 hours. [2]

The building was an angular, 9 story, silver and white structure, with zero carbon footprint; 130 m long by 48 m wide and 26 m tall in dimensions. The building could be produced, assembled economically and transported and at the same time, it provides low design effects.[2]

The plastic bottle bricks were called as polli bricks. They were very light, that small amount of silicon was used to during assembly to make them stay in place, and easier for workers to move the modules. [2]

There is one more advantage of recycling PET plastic bottles, it does not produce dioxins, when heated. The team uses the geometry of honeycomb to make the plastic bottles to fit each other. The plastic bottles are reshaped into hexagonal bricks with interlocking grooves, to fit like Lego blocks. [2]

The interlocking provides the prevention from wind and rain penetration into the walls; also, the structure then was able to withstand earthquakes and typhoons, also the winds up to 130 km per hrs. The building was also suitable for warmer and colder climates. In warmer climates, the polli bricks are filled with air, which acts as a natural barrier to the heat. In cold climates, the bricks are filled with water or sand, which absorbs heat from sun and provides natural heating. All this needed to be done by taking the modules somewhere empty site and then has to be filled up. The polli bricks had melting point of 280 degree Celsius.[2]

The building is acting as a "natural wind tunnel" as the NE prevailing winds are cool and need to be taken in as much as possible, as well as minimizes the sun exposure from the south side due to the shade provided from surrounded trees. [2]

GENERAL INFORMATION	
CLIENT	Miniwiz business group
PROJECT BUILT BY	Ar. Arthur Huang
BUILT YEAR	2010
TYPE	floral expo
LOCATION	Taipei, Taiwan
CURRENT USE	1. to stage fashion shows 2. International Flora Expo
BUILT UP AREA	6,250 sq. m.
MATERIALS USED IN BUILDING	steel frame structure, pet bottles
TOPOGRAPHY	plain terrain
STRENGTH OF BOTTLE BRICKS ACHIEVED	1.5 L plastic bottle has 27.39 N/mm sq.
TYPE OF BOND USED	interlocking and fixing stacking
NO. OF STOREYS	G + 8

Figure 12. information of Eco-ark, Taiwan

ANALYSIS OF ELEMENTS OF A BUILDING							
	FOUNDATION	PLINTH	COLUMNS	WALLS	CEILING/ROOF	OPENINGS	PARTITIONS
MATERIAL	-	-	steel	pet bottle sq. modules over steel frames	steel truss, corrugated sheets	steel frame and plastic bottles	pet bottle
LIFETIME	-	-	more than 100 years	more than 300 years	more than 300 years	more than 300 years	more than 300 years
SPAN	-	-	spaced @ 3.6 m	130 m total length and 48 m total width of building	-	-	-
HEIGHT / NO. OF FLOORS	-	-	26 m high	3.2 sq. m. module size, 26 m high	-	-	3 storeys high (2890 mm approx.)
AESTHETICS/STRUCTURAL	structural		1. aesthetics 2. structural	structural	structural	aesthetics	aesthetics
LOAD BEARING/NON-LOAD BEARING	load bearing			load bearing	load bearing	non-load bearing	non-load bearing

Figure 13. analysis of Eco-ark, Taiwan

From the above analysis table, it can be gathered that plastic bottles can be used to construct a 9 to 10 story high building. The building will use less energy, sustainable, lowers carbon footprint, thermally comfortable and will provide enough daylight through the translucent façade. The building has more than 300 years of lifetime. The building can withstand harsh climatic conditions and natural calamities. The load and cost from the whole building is almost half the load and cost from conventional building (building made from conventional building materials).

2.9.2 House by Ingrid, Caribbean

This house project is chosen as case study as the building material is plastic bottle as the major material. The house is built by the local people and is able to withstand the heat, climate and other factors of the city. The cost of construction and maintenance is very low which is affordable by poor families.

Ingrid is a lawyer by profession, but her passion to do something for the world took her in other line of interest. She helped many people who were in need of houses to live in. so, she used recycled materials to build the houses, including plastic bottles, manure, expired milk powder etc. by doing these works, she got invitation from many cities and also one from Haiti, which got hit by a devastating earthquake. [7]

For an area of around 170 sq. m., 36 thousand plastic bottles are required, bonded with concrete and a plastic net. The bottles are filled with discarded materials, coating is done with a mixture of expired milk powder, horse manure, linseed oil, cattle blood, cane molasses etc., and floor is laid by chopped rubber from tires[7]. The houses are built for small families of 4-5 persons.

GENERAL INFORMATION	
CLIENT	Organisation of American States
PROJECT BUILT BY	Ingrid Vaca Diez
BUILT YEAR	2010
TYPE	residence
LOCATION	Haiti, Caribbean
CURRENT USE	residence
BUILT UP AREA	1830 sq. ft.
MATERIALS USED IN BUILDING	rubber tires, plastic bottles, mud, sand, cement, wood, metal sheets
TOPOGRAPHY	flat terrain
STRENGTH OF BOTTLE BRICKS ACHIEVED	1. 250ml plastic bottle has 38.34 n/mm sq. 2. 1.5 L plastic bottle has 27.39 N/mm sq.
TYPE OF BOND USED	horizontal bottles stacking bond
NO. OF STOREYS	single storey

Figure 14. information of house by Ingrid, Caribbean

ANALYSIS OF ELEMENTS OF A BUILDING							
	FOUNDATION	PLINTH	COLUMNS	WALLS	CEILING/ROOF	OPENINGS	PARTITIONS
MATERIAL	-	-	1. bottle bricks, mud, cement, iron rod 2. concrete	bottle bricks, mud, cement, plastic rope	metal corrugated sheet	wooden windows and door frames and shutters	bottle bricks, mud, cement, plastic rope
LIFETIME	-	-	more than 300 years	more than 300 years	more than 30 years	more than 30 years	more than 300 years
SPAN	-	-	1. 650 mm dia. 2. 300 x 300 mm cross section	3000 mm between two columns	-	1080 x 100 mm	3500 mm between two columns
HEIGHT / NO. OF FLOORS	-	-	1. 3250 mm high 2. 3550 mm high	3550 mm high	-	1260 mm height	3550 mm high
AESTHETICS/STRUCTURAL	structural		1. aesthetics 2. structural	structural	structural	aesthetics	structural
LOAD BEARING/NON-LOAD BEARING	load bearing			load bearing	load bearing	non-load bearing	load bearing

Figure 15. analysis of house by Ingrid

The house of about 170 sq. m. has post and beam frame skeleton which is filled with the help of plastic bottle bricks to make the walls. The house is capable to withstand earthquakes, fires, floods, typhoons etc. It is thermally comfortable, cheap and affordable by a poor person itself. There is no environmental hazard from the reusing of plastic bottle bricks and also, no health effects to the habitants of the house.

2.9.3 Bottle school by Hug it forward, Quisaya, Guatemala

The bottle school has applied plastic bottles as the bricks to fill up the walls. The house is constructed over a contoured site, though the builders made the land flat. But the school is providing education to the local poor children. The project is compatible with the surroundings also.

The team-built schools which were sustainable in terms of life time, energy usage, carbon emission etc. The concrete frame is built as the load bearing element which will bear the live and dead loads of the nature and living beings. The empty spaces are get filled up with the bottle bricks as the filler material.

The bottle school has 3 classrooms, built using method of post and beam construction. The foundations, columns and beams are made of concrete with reinforcement bars. But the only difference between a conventional building and this bottle school is that instead of bricks or cinder blocks, eco bricks (plastic bottle bricks) are used to fill out the walls. [1]

The school has post and beam frame skeleton which is filled with the help of plastic bottle bricks to make the walls. The school is capable to withstand earthquakes, fires, floods, typhoons etc. It is thermally comfortable, cheap and affordable by a poor person itself. There is no environmental hazard from the reusing of plastic bottle bricks and also, no health effects to the habitants of the house.

GENERAL INFORMATION	
CLIENT	Ministry of Education
PROJECT BUILT BY	Hug it Forward
BUILT YEAR	2020
TYPE	elementary school
LOCATION	Quisaya, Guatemala, South America
CURRENT USE	elementary school
MATERIALS USED IN BUILDING	concrete, rebars, cement plaster, bottle bricks, chicken mesh, sand, trash
TOPOGRAPHY	site is contoured, but the project is built over a flat terrain
STRENGTH OF BOTTLE BRICKS ACHIEVED	1. 250ml plastic bottle has 38.34 n/mm sq. 2. 1.5 L plastic bottle has 27.39 N/mm sq.
TYPE OF BOND USED	vertical bottle stacking bond
NO. OF STOREYS	single storey

Figure 16. information of bottle school by Hug it forward

ANALYSIS OF ELEMENTS OF A BUILDING							
	FOUNDATION	PLINTH	COLUMNS	WALLS	CEILING/ROOF	OPENINGS	PARTITIONS
MATERIAL	concrete, rebars	concrete, rebars	concrete, rebars	bottle bricks, chicken mesh, cement for plaster	corrugated sheet	widows - iron frame with glass, door - metal flush door	bottle bricks, chicken mesh, cement plaster, concrete frame structure
LIFETIME	more than 30 years			more than 300 years	more than 30 years	at least 25 years	more than 300 years
SPAN	1200 X 1200 mm footing base	-	400 x 400 mm cross section	walls are divided into modules of 2550 x 150 mm approx.	-	window opening size - 2550 x 150 mm door opening size -	8500 x 150 mm
HEIGHT / NO. OF FLOORS	-	400 mm thick	4250 mm height	1650 mm height of one module, 4500 mm total height	-	1650 mm	4250 mm (height excluding beam)
AESTHETICS/STRUCTURAL	structural			bottle bricks are fillers in frame structure	structural	aesthetics	frame structure is structural and bottle bricks are fillers
LOAD BEARING/NON-LOAD BEARING	load bearing			non-load bearing	load bearing	non-load bearing	load bearing

Figure 17. analysis of bottle school by Hug it forward

2.9.4 Farm house, Nigeria

This farm house is chosen for the case study as it is completely built with plastic bottles as bricks for the walls, columns, partitions etc. this house is also built by local habitants. The need of the house is for unemployed public of Nigeria, which is solved with the help of this construction method.

The farm house in Nigeria was built by one of the local families for themselves. 23.1% of Nigeria's youth is unemployed and most of the population is homeless. So, some people tried to construct the house with the use of plastic bottles. The total cost was almost 1/3 of the cost of conventional building cost. [6]

The plastic bottle bricks are used as bricks, interconnected with ropes to hold them together, this helps to prevent cracks and also, the lifetime of these blocks is too much. A mud mixture is used to fill the plastic bottles. The foundation is laid. The house conducts far less heat and does not require air conditioning. [6]

The house uses plastic bottle bricks to make the walls, columns, laying of floors and partitions. The foundations of the farm house if of concrete reinforced with the iron rebars. The house is capable to withstand earthquakes, fires, floods, typhoons etc. It is thermally comfortable, cheap and affordable by a poor person itself. There is no environmental hazard from the reusing of plastic bottle bricks and also, no health effects to the habitants of the house.

GENERAL INFORMATION	
CLIENT	locals
PROJECT BUILT BY	Mohammed Sani
BUILT YEAR	2018
TYPE	residence
LOCATION	Yelwa village, Nigeria
CURRENT USE	residence
BUILT UP AREA	
MATERIALS USED IN BUILDING	concrete, rebars, bottle bricks, mud, sand, sludge
TOPOGRAPHY	flat terrain
STRENGTH OF BOTTLE BRICKS ACHIEVED	1. 250ml plastic bottle has 38.34 n/mm sq. 2. 1.5 L plastic bottle has 27.39 N/mm sq.
TYPE OF BOND USED	horizontal bottle stacking bond
NO. OF STOREYS	G + 1

Figure 18. information of farm house, Nigeria

ANALYSIS OF ELEMENTS OF A BUILDING							
	FOUNDATION	PLINTH	COLUMNS	WALLS	CEILING/ROOF	OPENINGS	PARTITIONS
MATERIAL	-	-	bottle bricks, concrete, mud, iron rod	bottle cricks, mud	wooden pitched roof	wooden windows and doors	bottle bricks, mud
LIFETIME	-	-	more than 300 years	more than 300 years	more than 30 years	more than 30 years	more than 300 years
SPAN	-	-	650 mm dia.	300 mm thick, 2250 mm max. length	-	window- 1050 x 100 mm door -	300 mm thick, 2250 mm max. length
HEIGHT / NO. OF FLOORS	-	-	2450 mm height of one floor	2450 mm height of one floor	ground floor slab is cast in concrete, for first floor wooden pitched roof is adopted	window- 1050 mm high door- 2200 mm high	2450 mm height of one floor
AESTHETICS/STRUCTURAL	structural			bottle bricks are used as filler in frame structure	structural	aesthetics	bottle bricks are used as filler in frame structure
LOAD BEARING/NON-LOAD BEARING	load bearing			non-load bearing	load bearing	non-load bearing	non-load bearing

Figure 19. analysis of farm house, Nigeria

2.9.5 Manav Sadhana Activity Centre, Ahmedabad

The project is chosen as the construction is done using 20 different waste materials, generates in Ahmedabad. Waste such as fly ash, dump fill site waste, crate packaging, plastic water bottles, glass bottles, rag, wrappers, metals crap and broken ceramic wares, compact disc and electronic hardware etc. [9] are recycled and reused to construct the center. The site area of the project is 1100 sq. m. and B.U.A. is 515 sq. m.

The Centre provides the facility of school for the young, vocational training center for the ladies, gymnasium for the men, crèche for the toddler, health camp on weekends, craft production unit for women and community center for festive celebrations and events. The center uses waste materials to build the walls, roofs, floors and fenestrations. This makes the building sustainable and environmentally friendly, thus, empowers the economics of the poor people around the center by providing them the opportunity in building construction. The project initially had activity center and later it also housed a creche to look away for young kids.

Materials and techniques for walls includes- cement bonded fly ash bricks, mold-compressed bricks made from landfill site waste residue, stabilized soil blocks, recycled glass bottles, recycled plastic bottles filled with ash and waste residue, and vegetable crate wood paneling in the inner partition walls. [9]

Materials and techniques for floors and slabs- filler slab with glass bottles, plastic bottles and bricks, stone slab, cement bonded particle board with clay tile cover, as well as light conduit pipe truss with G.I. sheet with clay tile roof. [9]

Materials and techniques for doors and windows- shredded packaging wrapper and coated paper waste as reinforcement substitute for fiber reinforced plastic (FRP), vegetable crate wood as a frame and oil tin container as blades make the ventilation louvers in the toilets. [9]

The building components were built using simple hand operated tools, waste material and local resources with the know-how knowledge. The components were all tested in labs and on-site explorations were done.

GENERAL INFORMATION	
CLIENT	Manav sadhna NGO organisation
PROJECT BUILT BY	Ar. Yatin Pandya
BUILT YEAR	2006
TYPE	Activity centre
LOCATION	Rama PirTekra, Wadaj in Ahmedabad
CURRENT USE	community providing education, vocational training, Gymnasium and health care facility, creche facility
BUILT UP AREA	515 Sq.mts.
MATERIALS USED IN BUILDING	Flyash, dump fill site residue, plastic bottles, glass bottles, crate wood, re bars, packaging wrappers, oiltin containers etc.
TOPOGRAPHY	Plain terrain
TYPE OF BOND USED	Stacking bond
NO. OF STOREYS	single story

Figure 20. information of Manav sadhana activity centre, Ahmedabad

III. Result

The buildings made from waste materials came into existence due to increase in waste generation, unemployment of public, increment in poor public, need for the sustainability etc. These are few reasons that buildings need to be built out of waste. Therefore, from all the case studies done above, inferences could be:

1. Foundation and plinth of the building should be cast in concrete and reinforced with iron rebars.
2. Columns can be built from bottle bricks, columns with circular and square cross sections can be built having 650 mm dia. And 300 x 300 mm (min.), 500 x 600 mm (max.) dimensions respectively. Max. height can be 3500 mm.
3. Beam and slab are built from concrete and reinforcement bars, max. thickness is 400mm and 300mm respectively.
4. Columns are spaced @ 3200 mm max. distance. This creates different modules within a wall.
5. The walls are filled with bottle bricks as filler. The plastic bottles are filled with mud, sand, trash etc. so that the bottles will not get collapsed. The average dimension of a bottle taken is 90 mm dia. And 300 mm height.
6. The bottle bricks are filled in two ways:

- Stacking the bottles just like the bricks with the help of cement mortar, directly in the empty space of the module. The bottle bricks are tied with the plastic rope from cap to cap to make them stand on their place.
- First a chicken mesh is fixed on the one side of the structure, bottles are placed vertically and tied to the mesh with the help of plastic ropes, cement plaster is applied in the gaps, chicken mesh is again fixed over the other side of the structure. In this way, the bottles get sandwiched between two chicken meshes.

7. Cement plaster is applied over the plastic bottles to get uniform finish; or one can leave the plastering.
8. Window and door openings can be provided by fixing sill and lintels. The window and door frames can be put off any material chosen by the client.
9. Roof of the building is constructed of corrugated sheets with metal frame skeleton. Pitched roof is provided in the above cases.
10. Maximum no. of floors constructed are 9 floors.

11. The buildings are thermally comfortable, can withstand the shocks of earthquake, floods, typhoons, wind with 13 km per hours speed etc.
12. The building can also resist the bullet attacks.
13. The preferred site topography is flat terrain.

3.1 Plastic waste

Except grade 6 and grade 7 of plastics, all grades of plastic are reusable. However, grade 1 of plastic is the most common grade which is recycled and reused in building material industry. The qualitative table clearly explains the nature and behavior of the plastic waste. The ease of workability of plastic waste is easy as it can be reused easily by common labor, creates no pollution and health effects. The plastic waste provides a wide range of uses when reused, the building from plastic waste offers great resistance to fire, bullets, natural calamities etc. and the most important aspect is that building does not creates hazard to environment and health after a long time.

The research paper is reusing the plastic waste which is easily available, easily affordable, easy to work with, less environment polluter, less human health effective etc. reusing the plastic waste means using the waste product directly as it is or by transforming the waste into pieces, fibers, aggregates etc. To build a building from the waste, detailed information about the material should be provided-

1. Compressive strength and load capacity: determine the strength provided by the unit or load that is bearable by the unit.
2. Cement sand ratio and water cement ratio: determine the mixing amounts of cement with sand and water with cement for the plaster.
3. Bond: type of bond to build a vertical plane with a unit
4. Time and speed of execution: how much labor is required to work with the material for easy execution and whether it is easy to work with the material or not
5. Resistance to earthquake: material is able to withstand the shocks or not
6. Cleanliness and beauty of the work: output would be neat and tidy in appearance or not
7. Material wastage: how much material would get waste during the execution
8. Flexibility: determines whether the material can be used easily in any place, it can also be defined in terms of dimensional compatibility.
9. No. of floors: how much height is attainable by using the material
10. Span: max. length that can be achieved
11. Load bearing/non-load bearing: whether the material will exert load or not after building the elements
12. Structural/aesthetics: whether the material would be used as a structural element or for aesthetics only.
13. Impact over Environment: whether the material is environment friendly or not

SPECIFICATION OF PLASTIC WASTE MATERIAL			
PARAMETERS	CONSIDERATIONS	PLASTIC BOTTLE BRICK	CLAY BRCK
COMPRESSIVE STRENGTH AND LOAD CAPACITY	250 ml plastic bottle and 1.5 l plastic bottle	250 ml bottle has 38.34 N/mm sq. 1.5 l bottle has 27.39 N/mm sq.	8.58 N/mm sq.
CEMENT SAND RATIO	-	01:02	01:02:04
WATER CEMENT RATIO	of plaster	0.3	0.5
BOND	bond between building blocks	stacking bond	English and Flemish bond
TIME AND SPEED OF EXECUTION	5 persons team one working day	15% faster	120 sq.m.
RESISTANCE TO EARTQUAKE	earthquake is directly proportional to weight of structure	low and integrated weight without falling debris	falling debris is harmful for the habitants
CLEANLINESS AND BEAUTY OF WORK	-	very clean execution	needs skilled labour for clean work
MATERIAL WASTAGE	during application	no wastage	high and unusable
FLEXIBILITY	-	high flexibility	low flexibility

Figure 21. specification of plastic waste as building material

PLASTIC WASTE					
CATEGORY OF WASTE	NON-BIODEGRADABLE WASTE				
ORIGIN OF WASTE	municipal solid waste				
AMOUNT OR PERCENTAGE OF GENERATION	5.47 lakh tonnes in uttar pradesh				
BEHAVIOUR WITH THE WASTE PRODUCT	1. burning	2. incomplete combustion	3. transforming into fibres		
ALTERNATIVE USE OF WASTE PRODUCT	1. bricks	2. concrete aggregate	3. fibre reinforcement in structural concrete		
REASON OF USING WASTE PRODUCT	1. lightweight	2. strong	3. clear	4. longer life span	5. easy to recycle or reuse
RECYCLING OR REUSING TECHNIQUE	1. mechanical recycling	2. chemical recycling	3. energy recovery		
LIFE TIME OF ALTERNATE PRODUCT	300 - 500 years				
ADVANTAGE OF ALTERNATIVE PRODUCT	1. reduces water pollution	2. conserves natural resources			
DISADVANTAGE OF ALTERNATIVE PRODUCT	1. VOCs (volatile organic compounds) released from plastic recycling harm the environment	2. generates carbon emissions	3. does not guarantee good quality products	4. increase low quality jobs, These include sorting the garbage, cleaning toxins and doing the other manual and the intensive labor	
IMPACT OVER ENVIRONMENT AND HEALTH	heart diseases, asthma, nausea	lungs damage, neurological problems etc.			
EASE OF WORKABILITY					
RECYCLING OR REUSING TECHNIQUE USEFULNESS					
SCOPE OF ALTERNATIVE USES					
FIRE RESISTANCE OF BUILDING					
HAZARDS OVER ENVIRONMENT AND HEALTH AFTER YEARS					
EASY	**YES**	**MANY**	**HIGH**	**LOW**	

Figure 22. qualitative information of plastic waste

3.2 Construction and demolition waste

The waste is easy to reuse but requires proper refurbishment (for the components which are directly used from the demolition waste). However, reusing of aggregates is easy to reuse without any refurbishment. The brick and masonry can be reused directly in the form of ballast in filling up of the foundation pit. The structures provide good resistance against fire and is less prone to effect environment and human health.

CONSTRUCTION DEMOLITION WASTE				
CATEGORY OF WASTE	INERT AND NON-BIODEGRADABLE WASTE			
ORIGIN OF WASTE	from structures that detoriorate in 10 to 20 years			
AMOUNT OR PERCENTAGE OF GENERATION	10-20 % of the municipal solid waste (excluding large construction projects)	10-12 million tons of waste annually		
BEHAVIOUR WITH THE WASTE PRODUCT	1. sorting	2. crushing	3. sieving	
ALTERNATIVE USE OF WASTE PRODUCT	concrete with wood waste is of low strength	concrete with polystyrene can be used to obtain prefabricated units		
REASON OF USING WASTE PRODUCT	do not cause odour or pollution	transportation cost is also reduced		
RECYCLING OR REUSING TECHNIQUE	bricks, wood, metal, titles are recycled	Recycling of concrete and masonry waste done abroad like U.K., U.S.A. etc.	concrete from demoilition can be used as an aggregate	as filler or replcement of fine aggregates in concrete
LIFE TIME OF ALTERNATE PRODUCT	more than 30 years			
ADVANTAGE OF ALTERNATIVE PRODUCT	does not create chemical or biochemical pollution	Uses Less Energy		
DISADVANTAGE OF ALTERNATIVE PRODUCT	consuming enormous quantities of stone, sand and drinking water	consume huge quantities of cement	cause obstruction to traffic	
IMPACT OVER ENVIRONMENT AND HEALTH	chokes surface drains	fine particles of dust cause air pollution in the region		
EASE OF WORKABILITY				
RECYCLING OR REUSING TECHNIQUE USEFULNESS				
SCOPE OF ALTERNATIVE USES				
FIRE RESISTANCE OF BUILDING				
HAZARDS OVER ENVIRONMENT AND HEALTH AFTER YEARS				
EASY	**YES**	**LIMITED**	**GOOD**	**LOW**

Figure 23. qualitative information of construction and demolition waste

3.3 Transportation industry waste

The transportation industry waste after get dismantled, is difficult to handle, as the mechanical parts are very small except the outer body of steel and cast iron. To reuse the automobile directly, it will get handled easily. Therefore, the scope of reuse is wide. The tires are sensitive to fire while other iron and steel parts are less sensitive to fire. The environmental impact and health hazards are very less from this waste.

TRANSPORTATION INDUSTRY WASTE				
CATEGORY OF WASTE	HAZARDOUS WASTE			
ORIGIN OF WASTE	1. freight transport, hicle maintenance and cleaning, freight handling and warehousing operations.	2. repair and servicing of vehicles		
BEHAVIOUR WITH THE WASTE PRODUCT	1. in natural form	2. cut in aggregates	3. in powder form	
ALTERNATIVE USE OF WASTE PRODUCT	1. for fixing and sealing soils in agricultural domain	2. in hydraulic domain (retaining walls, breakwaters)	3. light concrete	4. pavements for roads
REASON OF USING WASTE PRODUCT	great resistance to temperature variations	reduced noise	lower maintenance cost	
RECYCLING OR REUSING TECHNIQUE	as a lightweight filling material for soil reinforcement	as replacement of sand in glass fibre reinforced composite	as filler or replcement of fine aggregates in concrete	
ADVANTAGE OF ALTERNATIVE PRODUCT	increases the capacity to absorb energy from impacts	reduce damage from collisions	increase deformability and ductility of concrete	
DISADVANTAGE OF ALTERNATIVE PRODUCT	concrete with used tyre presented a decrease in mechanical properties	contaminate groundwater		
IMPACT OVER ENVIRONMENT AND HEALTH	1. hazard fire which is almost impossible to extinguish	Landfills can also emit harmful gases into the atmosphere		
EASE OF WORKABILITY				
RECYCLING OR REUSING TECHNIQUE USEFULNESS				
SCOPE OF ALTERNATIVE USES				
FIRE RESISTANCE OF BUILDING				
HAZARDS OVER ENVIRONMENT AND HEALTH AFTER YEARS				
DIFFICULT	**YES**	**MANY**	**LOW**	

Figure 24. qualitative information of transportation industry waste

IV. Discussion

Among the 8 waste materials, three waste materials- plastic waste, construction demolition waste and transportation industry waste, can be reused for the application in building material industry, which is deduced from the SWOT analysis.

When plastic bottle bricks are used to build any structure without any supporting skeleton, construction of 3 floors are preferred; and when plastic bottles are used to build any structure with a supporting skeleton, construction of 9 to 10 floors can be done.

The strength of column build from plastic bottle bricks, is inversely proportional to the size of bottles. If for a structure, concrete frame structure is going to be build, cross-section of column should be 300 mm x 300 mm at least and cross-section of beam should be 300mm x 400mm. The maximum distance between two columns of plastic bottle brick should be at least 2.5m and 4m maximum (plane to plane) and maximum height preferred is up to 3 floors.

SPECIFICATION OF PLASTIC WASTE MATERIAL IN BUILDING		
PARAMETERS	CONSIDERATIONS	SPECIFICATIONS
COMPRESSIVE STRENGTH AND LOAD CAPACITY	250 ml plastic bottle and 1.5 l plastic bottle	250 ml bottle has 38.34 N/mm sq. 1.5 l bottle has 27.39 N/mm sq.
CEMENT SAND RATIO	-	01:02
WATER CEMENT RATIO	of plaster	0.3
BOND	bond between building blocks	stacking bond
TIME AND SPEED OF EXECUTION	5 persons team one working day	15% faster
RESISTANCE TO EARTQUAKE	earthquake is directly proportional to weight of structure	low and integrated weight without falling debris
CLEANLINESS AND BEAUTY OF WORK	-	very clean execution
MATERIAL WASTAGE	during application	no wastage
FLEXIBILITY	-	high flexibility
COLUMN TO COLUMN DISTANCE	Plane to plane	2.5 to 4 m (max.)
SIZE OF OPENINGS	-	as per requirements
SIZE OF PANEL	one module of bottle brick assembly	2.5 m X 2.5 m (max.)
MAXIMUM HEIGHT	of single floor	4500 mm
COLUMN CROSS SECTION	Of 250 ml plastic bottle bricks	650 mm dia. For circular column is min. and 300 x 300 mm for square column (min.)

Figure 25. specification of plastic waste material in building

The construction demolition waste can be used as an admixture in concrete mixture, ballast can be used as filler in foundation plinth, fine aggregates can be used in cement plaster. The structure build from waste materials as an alternative building material are 18% cost saver, 20% stronger(mokhtar, 2015), has ability to natural calamities, do not produce carbon emissions and greenhouse gases, helps in reducing natural resources mining, stable for up to 100 years and more and is considered as bioclimatic in nature, are the qualities of a building from alternative waste materials (plastic and construction demolition). The structures from 3 waste materials should be built in places like cold regions, hot regions, warm and humid regions, defense regions, earthquake prone regions, typhoon prone regions, strong winds prone regions etc. for example-

Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Leh Ladakh, North Sikkim are cold regions; Rajasthan, Maharashtra, Madhya Pradesh, Andhra Pradesh, Gujarat are hot regions; Delhi, Patna, Srinagar, Kohima, Puducherry, Guwahati, Gangtok, Shimla, Dehradun, Imphal and Chandigarh are earthquake prone regions etc. are some few mentions of the cities where the structures from the 3 waste materials will be very effective. The terrain for the structure can be contoured or plain.

V. Conclusion

The wastes that generated from households and industries are considered as worthless. Also, the wastes have substantial impacts over the environment and health, but only when the waste is not managed properly. Reusing the wastes in building material industry and construction industry can help in reducing the percentage of waste generation. Reusing the waste is the better solution than recycling, as recycling the wastes requires infrastructure and resources, which can increase carbon footprint and energy will get lost. The wastes from industry and household wastes that can be reused are plastic waste, construction demolition waste and transportation industry waste, found out from SWOT analysis. Plastic waste and construction demolition waste has a range of alternative uses as a building material than transportation industry waste. The structures from 3 waste materials should be built in places like cold regions, hot regions, warm and humid regions, defense regions, earthquake prone regions, typhoon prone regions, strong winds prone regions etc. The structures are easy to construct, do not requires skilled labor, can be affordable by an unemployed person and the waste material is easily available.

VI. The way forward

Since, the structures from three waste materials- plastic waste, construction demolition waste and transportation industry waste can be built with better structural values, environmental stability can also be

found, are cheap and lightweight etc. are the qualities and characteristics of the structures constructed out of waste (only reusing the waste). However, simulations should be done on for the found out structural dimensions of the structural elements of the building. Simulations should also be done over the thermal performance, energy efficiency and structural behavior of the building. The structure should also be tested for the natural calamities.

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