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THE CIRCULAR ECONOMY OF DHARAVI: MAKING BUILDING MATERIALS FROM WASTE

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ABSTRACT

As developing nations continue to progress, people of these countries face problems of shortages in building materials and rising production of solid waste. The purpose of this research study is to explore the establishment of a circular economy by recycling/reusing solid waste as an alternative building material. Focused on the slum of Dharavi in Mumbai, a settlement famous for its existing recycling business, this research explores the concept of a circular economy utilizing local informal labor and the flow of waste materials in the slum. This research presents an analysis of the concept of a circular economy, the history of the Dharavi slum, the imposed governmental policies, existing building materials used in makeshift houses, and case studies where waste is reused as a building product. This research identifies the gaps, advantages, and disadvantages related to how and where the building materials from the case studies could be adapted in the context of the Dharavi slum. This research study contributes to the development of strategies for the application and reinforcement of a circular economy of building materials from waste in the informal economy.
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1. INTRODUCTION

1.1 PROBLEM STATEMENT

The building industries in developing nations are currently burdened with the problems of the scarcity of financial and material resources. The demand for building products greatly outweighs the supply, resulting in delays, wastage, high prices, and black marketeering (Razvi, 2002). The volume of physical resources needed to develop the infrastructure to meet the rising standard of living of the middle class puts severe pressure on the resources of a country. These problems continue to be exacerbated by the rapid urbanization process. In developing countries, the urban population is growing two to three times faster than the rural population (United Nations Centre for Human Settlements, 1996). The rapid urbanization causes shortages of standard housing, rapid depletion of natural resources such as forest and fertile agricultural land, air and water pollution, and increased waste production in the urban areas (Ofori, 2000). Moreover, increased consumption rates lead to massive waste production which is sent to landfills. Only a small fraction of the industrial waste from landfills is recycled while the rest is a loss of natural resources. Some of the waste is even sent to incineration plants, which adds to the problem of air contamination with toxic fumes as well as global warming. The growing problem of landfill spaces or developing incineration plants in new locations cause developed countries to export trash to developing nations such as China, India, and Africa where laws regarding waste treatment and disposal are less stringent. The existing linear industrialized model catering to increased consumption is unsustainable, and there is a dire need for a radical shift in prevailing models of human production and consumption to prevent the negative consequences affecting the ecological balance as well as the welfare of the people.

The global report by the United Nations Centre for Human Settlements (1996) points out that the problematic condition of human settlement urgently needs creative innovation and action. This change can be achieved by making required choices for a balanced use of resources, considering for finite nature of ecosystems, and moving away from existing wasteful living
standards. This investigation into alternative building technologies using solid wastes has the potential to contribute to solving the problems mentioned before. Alternative building technologies or material from solid waste diminish the dependency on raw and natural resources for construction material. These technologies can also meet the growing needs of the building industries by utilizing locally available materials with the help of the skills and labor of the people, creating jobs in the process, and reducing the negative impact on the environment.

This research analyzes the concept of a circular economy of building materials in the context of Dharavi, which is an informal slum in the heart of the metropolitan city of Mumbai in India. Dharavi faces problems of urbanization - the lack of housing infrastructure and proper living conditions. Dharavi has an informal market parallel to the formal economy of the city that is estimated to be around one billion dollars annually (Chandran, 2016). Dharavi is selected for investigation due to the fact that it has a thriving informal recycling business of inorganic waste. Considering the established circular economy of recycling and reuse, this research further explores reuse opportunities of building materials from inorganic waste in the context of the informal slum of Dharavi.

1.2 SIGNIFICANCE OF RESEARCH

The informal slum of Dharavi has a crude circular economy in place whereby solid wastes are being reused and recycled. This research study looks into the possibility of establishing a circular economy of alternative building materials from the existing inorganic waste materials in the slum that can be used to meet not only the demand for building materials but can contribute to the formal market. This research thus addresses much greater global concerns of reducing dry waste from landfills, conserving natural resources, saving energy of production of the formal building materials and exploring new employment opportunities for the inhabitants of slums. The findings of this research will be useful in other informal settlements to identify the scope of a circular economy that uses building materials from waste in their own context, and can also help to
identify the associated needs and obstacles for the transition to a circular economy, which has positive social, economic and environmental benefits (Razvi, 2002).

1.3 WHY DHARAVI?

Dharavi is an informal settlement in the heart of Mumbai in India. It is a kind of township of its own covering an area of 525 acres with a population of more than 1 million people (World Population Review, 2018). The sheer scale of the number of people living in the slum has created a market having its own demand. The market runs on innovative entrepreneurial spirit of the people to support themselves. A parallel informal economy by the massive labor pool is formed, characterized by innovation, recycling, and reuse which are the traits of a circular economy.

This research involves a study of the potential use of a circular economy to improve housing conditions of the people of Dharavi, the application of which has the added positive attributes of minimizing the environmental impact and creating new employment opportunities. Again, Dharavi is a very famous informal settlement due to its thriving economic activities where dwellers are mostly responsible for their own employment and not solely dependent on the formal city for employment. It is a plan-free, chaotic, dynamic, and dense community which is often seen by many architects and planners as an efficient model due to its common life-work spaces cutting down on transportation needs. Kevin McCloud, the BBC host of Grand Design, stayed in the slum for a few days to experience the lifestyle of the inhabitants (BBC News, n.d.). McCloud lauded the culture of sharing and the flexible use of resources by the families in Dharavi, and he aimed to translate this knowledge in his own design practice in Britain. The slum presents with an opportunity for learning about the ethos of sharing. Moreover, the culture of reuse of material is very much needed in a world of depleting finite resources.

This research tries to contribute by identifying potential opportunities of a circular economy for creating building products out of existing materials in the inorganic waste inventory of a
particular slum. The logistical findings or recommendations will be useful and informative to scale up to other informal housing situations across the world as one billion people out of the world population of seven billion is estimated to live in these kinds of informal settlements (UN Habitat, 2015).
2. LITERATURE REVIEW

2.1 THE CONCEPT OF CIRCULAR ECONOMY

2.1.1 BACKGROUND

The linear industrial revolution focused on increasing efficient manufacturing process has made it possible for human civilization to overcome scarcities of goods in people’s daily lives, but its success creates a saturated market and unmanageable waste, which are incompatible with the limited carrying capacity of the earth (Stahel, 2017). During the last hundred years, prices for energy and materials have constantly decreased but it is expected that resource price will constantly increase in the 21st century due to the finite nature availability of resources. In a linear industrial economy, the manufacturers are only involved to the point of sale of a product, after which ownership and liability are passed on to the buyer. The buyer uses the product for some time and discards the whole product away because of either being outdated by the current market or having a broken part. People are mostly unaware of what happens to the waste when it leaves their houses. The existing consumption practices of various material resources is linear and wasteful. The outcome of consumption in an industrial economy is not valued as a resource but seen as a product excluded from the cycle of the economic system (The Story of Stuff, 2007). Furthermore, people end up paying to the authorities to discard the product as the product usually ends up having no value at the end of its first use cycle.

2.1.2 PROBLEMS WITH A LINEAR MODEL

The global system of production is predominantly linear which is a take, make, and dispose method enabled by a century of declining commodity prices (GMO Quarterly Letter, 2011). Waste is generated as companies plan obsolescence in their products, generating long term sales volume by reducing time between repeat purchases (Bidgoli, 2010). This leads to problems of two
major kinds, one where the finite natural resources are depleted, while the other is the environmental damage caused by massive amounts of non-biodegradable and toxic substances that are being dumped in the landfills and ocean beds. Currently, the world extracts around 45 to 60 billion tons of resources per year. The current growth trends suggest the figure could go up to 140 billion tons by 2050 (UNEP, 2011). The finite natural resources are depleting due to the current linear economy. The increasing demand for raw materials from the world’s emerging economies has resulted in high and volatile prices for many basic resources. The manufacturing companies do not enjoy resource security as they used to. Since the Second World War, companies in competition have tried to reduce the cost of goods by moving production to lands where they enjoy cheap labor, and that is why most of the world’s manufacturing companies are in China. The problem with this practice will arise when income in emerging economies increases and the developed nations will cease to enjoy this source of cheap labor.

In the past three decades, one-third of the earth’s natural resources have already been exploited. The United States of America has 5% of the world’s population and uses up to 30% of the world’s resources. If all the people in the world consumed at this rate, it is estimated that humans would require at least three to five planets to sustain this existing lifestyle (The Story of Stuff, 2007). As western economies deplete their natural resources, they depend on natural resources extracted from developing countries. Europe imports 60% of its fossil fuels and metal, while the European Union has listed 20 materials in their economy as critical for security of supply (McKinsey Center for Business and Environment, 2016). Moreover, as developed economies run out of landfill grounds, waste materials are being sent back to the developing nations. China, which is a major destination for the inorganic waste from developing world, recently has declared a ban from January 1, 2018 on foreign waste citing the reason of waste containing too many non-recyclable materials, some of which are hazardous in nature (Profta & Bums, 2017). It is to be noted that energy is used not only in processes of mining and extraction, but also in exportation, transportation, and incineration of wastes resulting in more greenhouse gases. Furthermore, toxic chemicals from waste leach into the ground and contaminate the groundwater and surface
water destroying ecosystems and endangering humans and other living species. Current habits have led to landfills being untapped sources of resources. A linear system based on consumption rather than on the restorative use of non-renewable sources entails significant losses of value and negative effects all along the material chain (Ellen MacArthur Foundation, 2013). Major strides have been made in resource efficiency in production and exploring new forms of energy, but less thought has been given to systematically designing out material leakage and disposal.

2.1.3 THE CIRCULAR MODEL

A circular economy is an alternative to a traditional linear economy in which we keep resources in use for as long as possible, extract maximum value from them while in use, and then recover and regenerate products and materials at the end of each item’s service life (WRAP, n.d.). It is conceived as a continuous positive developmental cycle that preserves natural capital, optimizes resource yields, and minimizes system risks by managing finite stocks and renewable flows (Sukhdev, Vol, Brandt, & Yeoman, 2017). Analogies can be drawn from nature’s ecological cycles where end products as well as byproducts of a system are used up in other processes in a perpetual chain.

The idea of a circular economy has been shown to resonate for quite some time by architects and economists. Kenneth Boulding (1966) in his paper “The economics of the coming spaceship Earth” presented the idea of stable, closed-cycle, high-level technology. Buckminster Fuller also echoed that “Pollution is nothing but the resources we are not harvesting. We allow them to disperse because we have been ignorant of their value” (Farrell, 1971). The concept of a circular economy was also echoed and raised by two British environmental economists David W. Pearce and R. Kerry Turner (1990) in their book Economics of Natural Resources and the Environment. Similar trends of thought were introduced such as the Cradle to Cradle concept by German chemist Michael Braungart and American architect William McDonough (2002; 2007);
Performance Economy by Walter R. Stahel (1981); Biomimicry by Janine Benyus (2002); and other trends such as Industrial Ecology, Natural Capitalism, Regenerative Design, and Blue Economy.

Cradle to Cradle – This concept considers all material to be into two categories of nutrients: technical and biological. Everything is a resource for something following the parallels of natural systems where waste of one system becomes food for another. Everything can be designed to be disassembled and safely returned to the soil as biological nutrients or re-utilized as high-quality materials for new products as technical nutrients without contamination (McDonough & Braungart, 2002).

Biomimicry – This concept looks at nature’s time-tested patterns and strategies as sustainable solutions to global human problems and challenges. Natural solutions are being translated into technical, industrial, and commercial spheres by investigating nature (Benyus, 2002).

Performance Economy – This concept envisions an economy in closed loops where manpower is substituted for energy. The goals are product life extension, durable goods, reconditioning activities, and waste prevention. It focuses on the importance of selling services rather than products (Stahel & Reday-Mulvey, 1981).

Industrial Ecology – It is the study of material and energy flows focusing on connections between operators within industrial ecosystem in which waste serves as an input. It eliminates the notion of an undesirable by-product (Ellen MacArthur Foundation, n.d.).

All these concepts of circular economy have the same underlying idea where waste is considered as a resource and fed into other use cycles. It is an approach of closing loops in industrial systems and minimizing waste having social, environmental and economic benefits. The studies of Walter R Stahel (2015; 2017), a Swiss architect and co-founder of the Product-Life Institute in Geneva, were seminal in developing and popularizing the model of what is currently called a circular economy. Walter R Stahel coined the term Cradle to Cradle, and the approach was further developed by William McDonough and Michael Braungart (2002; 2007).
In the concept of The Performance Economy manpower is substituted for energy (Stahel & Reday-Mulvey, 1981). This concept as proposed by Walter R. Stahel seems more relevant to the context of Dharavi as the slum is marked by massive manpower resources involved in recycling waste resources into another use cycle. The circular model falls into two groups according to Walter R. Stahel (1981) where one extends service life of a product by repair, upgrades, retrofitting, remanufacture, and re-use while the other relies on turning old products into new resources by recycling. The refurbishing and recycling method calls for a need of skilled jobs in local labor. It marks the shift to a model of stewardships in place of ownership whereby consumers become users and creators. The materials at the end of its life is utilized in another. Thus, the concept eliminates “waste” out of the economy. Products are designed and optimized for a cycle of disassembly and reuse. In the case of consumable products, the design of the product should avoid incorporating materials which are toxic in nature.
2.1.4 REQUIREMENTS TO ESTABLISH A CIRCULAR MODEL

The circular economy is based on a service-based model where selling services rather than goods is a preferred method. Reprocessing of goods and materials generates jobs, saves energy, and reduces resource consumption and waste. Rethinking the positives and negatives of every alternative supply chain needs to be studied carefully before one is implemented. It requires research and collaboration from various disciplines of material scientists, chemical scientists, business and economic graduates alike.

Social networks and media can play a vital role in the transition and can mobilize a bulk of the population to embrace a culture of circular economy. Highlighting benefits of projects
applying circular principles through mass media channels is essential to mobilizing action. A lack of familiarity and fear of the unknown could be the cause of why the circular economy has been slow to gain traction (Stahel W. R., 2015). Broad support from society involving NGOs, businesses, trade unions, research institutions and other stakeholders are necessity drivers of a closed loop economy. For the circular economy to work it needs commitment and involvement of different groups of people. Policy-makers’ role is to provide the framework conditions, predictability, and confidence to businesses; to enhance the role of customers; and to set out how citizens can secure the benefits of changes under way (European Commission. Environment Directorate-General, 2014). Our culture and attitude are essential for a responsible transition. This concept questions the measure of Gross Domestic Product as the only indicator of progress and standard of living. Due to increased economic activity there is a loss of resources, loss of healthy lifestyles, negative social and environmental effects, cultural depletion, and reduction of the quality of life, but these negative consequences are unfortunately ignored by the seemingly convincing single figure of the economic concept of GDP.

There are differences of ideas in the means to transition to a circular economy. It can be argued that recycling and reusing is something which is not worth the effort as it just slows the inevitable destruction of the earth as pointed out in the book Cradle to Cradle (McDonough & Braungart, 2002). However, transition cannot happen overnight as rethinking and redesigning an entire supply chain is a slow process as it first involves a cultural change and outlook followed by brainstorming various ways to recirculate the products in a continuous loop. It requires a lot of intellectual effort and involvement of chemists and material scientists to figure out the reusability of different parts of a product at the end of each life process without causing any damage or harm to the environment and users. Moreover, the entire process needs to be profitable for the ones who are implementing it. The concept of an ideal cyclical model where the idea of recycling does not exist, should not discourage the efforts of re-using and recycling as we are not starting at an ideal fresh planet. The earth is littered with massive amounts of waste. A “clean-up” of oceanic plastic, mining of landfill sites, and re-use of existing materials and structures should put
the ignored waste materials into circulation until it is figured out how they can be discarded safely to the biosphere.

2.1.5 INITIAL ADAPTATIONS OF A CIRCULAR ECONOMY

Countries across the globe have started developing strategies to move to a circular economy. Some European countries such as Denmark, the Netherlands, Scotland, and Sweden along with Japan are far ahead in adopting circular economy legislation (Braw, 2014). China, South Korea, and the United States have started research on establishing circular economies while the other European countries are also following steps in that direction. The European Union adopted a Circular Economy Package in December 2015 to transition to a circular economy. The World Circular Economy Forum was held in June 2017 in Finland attended by delegates of business leaders, policymakers, researchers, and innovators from more than 100 countries who shared their industry knowledge and expertise on how to achieve this goal. The forum also created a website to share experiences of the various solutions achieved in businesses for creating value and generating growth along with new employment opportunities (Department of Communications, 2018).

Companies including Ellen MacArthur in the UK have been established since 2000 with the aim of accelerating the transition to a circular economy. The company works on a strategic level with big multinational company names such as Google, H&M, Philips, Nike, Arup, Unilever, and others to explore the potential of circular economy for value creation. Green Alliance, a charity and independent organization in the UK established with a focus on achieving environmental solutions, works with influential leaders in business, NGOs, and politics to trigger new thoughts and ideas about environmental policy and to provide support for environmental solutions. The organization in their report, “Re-Inventing the Wheel: A Circular Economy for Resource Security,” calls for use of economic instruments such as taxes, charges or subsidies, or the removal of any of these to influence and mobilize the transition to a circular economy. A transition relies on system-
wide innovation, by aiming to redefine products and services to design waste out and to minimize negative impacts, and thus helping to build economic, natural, and social capital (Ellen MacArthur Foundation, n.d.).

Strong government support is a necessity for its success, which can be seen in some Asian and European countries such as China, Japan, Denmark, and the Netherlands. Japan sits on islands with extremely limited resources and thus has been developing solutions since the 1980s. The country boasts impressive figures in terms of recycling. It is estimated that 80% of car parts and 98% of metals are recycled in Japan. The recycling industry employs 650,000 people and contributes 7% of its GDP (Cord, 2017). The Chinese Government has an association named the China Association of Circular Economy which organizes trips to different countries to explore and learn the best circular practices in other countries. The government has imposed various policies which trigger the transition. Some policies are incentives which impose lower taxes on resource recycling and labor, lower prices for cleaner technologies, and penalties for pollution. In Europe, the automobile sector spends a significant amount on research and development to reduce the carbon footprint of the production phase by efficiently remanufacturing and repairing machine parts. This circular approach reduces energy consumption up to 80% compared to forging new parts, reduces overall waste by 70%, and reduces significant water and chemical use (European Automobile Manufacturers Association, n.d.). Even SpaceX, a private American aerospace and space transport manufacturer, focuses on reusing refurbished rocket launchers that cut a significant percentage, 30 percent, of blastoff costs and moreover reduces generation of space-trash and debris caused by conventional rockets, which threaten future space missions and the existence of present satellites (Ferris, 2017). Re-use opportunities exist such as charity shops, architectural salvage, auctions, garage sales, boot markets, eBay and Craigslist sales, Freegle in UK, and others which contribute to a circular economy. Other examples of circular economy can be found in the activities of some companies offering repair, bring-back schemes, re-use incentives, and upcycled products. Further instances of circular practices include Adidas’ training shoe developed in partnership with Parley for the Oceans, Apple’s Renew & Recycling, H&M’s
search for closed loop textiles, and Elvis & Kresse’s use of reclaimed fire hoses in fashion accessories.

The Cardboard to Caviar project initiated by Graham Wiles of the Green Business Network exemplifies how the establishment of a circular loop using waste as a nutrient has social, environmental, and economic benefits and presents opportunities for growth by incorporating byproducts from other systems as part of the main cycle (Pawlyn, 2011). The project started from a recycling initiative by involving people with disabilities to collect waste cardboard from shops.
and restaurants in Northern England to be shredded and sold to equestrian centers as horse bedding. After its first use as bedding the cardboard is composted by vermiculture. The surplus worms from vermiculture are then fed to Siberian sturgeon in fish farms established by Graham Wiles involving recovering heroin addicts. Since the fish farm attracted youngsters, they were involved in growing vegetables and taught about healthy eating. The vegetable waste was used to supplement the worms and reduce the dependency on commercial fish food. As fish growth slowed in winter, an adjacent 10 hectares of industrial land owned by Yorkshire Water was given to the project to plant short rotation willow to feed a biomass boiler to keep water warm in winter. A filtration system using reclaimed water storage tanks was used which yielded filtered water having high levels of nitrates and phosphates. The water is then fed into linear tanks planted with watercress, a food product which absorbed most of the nutrients leading to form clean water for the fish tanks. The sludge from the filtration system was used into worm composting beds as well as put into buckets of water to attract mosquitoes for a regular supply of larvae for the fish. A large part of the land was planted with fruit trees. Clover provided ground cover and fixed nitrogen in soil supporting plants that provide pollen for a thriving colony of bees (citation needed here).

The project, apart from being able to turn a waste industrial field into a thriving ecosystem producing the high value product of caviar to be sold back to the restaurants, was successful in rehabilitating addicts. It boasted an 80 percent success rate compared to conventional rehabilitation programs that have a 95 percent failure rate (Pawlyn, 2011). Thus, the project shows how a small loop can add up to contribute and be a part of other systems having positive ecological, environmental and sociological impacts.
2.2 CIRCULAR ECONOMY CONTEXTUALIZED TO INDIA

2.2.1 INDIA’S ECONOMIC GROWTH AND RISING URBANIZATION

India is a developing nation with economic growth of 7.2 % at the year end of 2017, establishing India’s rank as the fourth largest growing economy (Gray, 2017). In 2018, India is projected to rank as the fifth largest economy in the world, overtaking the UK and France (Babones, 2017). Indian cities contribute to about 2/3 of the country’s economic growth. They are
recipients of the Foreign Direct Investment and a place for innovation and technology. A massive migration to towns and cities by people in search of economic opportunities has posed unprecedented challenges of providing housing and infrastructure to the people. It leads to the development and growth of informal settlements where people are forced to live in improper living conditions due to lack of resources. In addition, the Indian middle class has doubled its size between 2001 and 2010 leading to an increased consumption pattern (The World Bank). The industrial and the service sectors contribute to higher shares of employment and Gross Domestic Product, but these sectors are resource intensive. Thus, this rapid growth of the economy poses great risk for resource security.

2.2.2 MATERIAL RESOURCE CONSUMPTION IN INDIA

In India, the per capita consumption of materials is low but due to the large population and rapid growth of the middle-class, India’s total resource material consumption is quite high, making it the world’s third largest consumer of materials (Indo-German Environment Partnership, 2013). Increased domestic resource extraction due to resource demand has led to serious environmental concerns of degradation, displacement, and loss of livelihood as most of the mineral reserves are in biodiverse forests, watersheds, and lands inhabited by indigenous people. Moreover, the mining industry is energy intensive, and thus it is one of the major factors associated with greenhouse gas emissions. India depends mostly on products that are extracted in the country, but with rising demand India’s net imports have steadily increased in the past decade. In the cases of certain minerals such as copper, cobalt, and nickel, India imports more than 95% of the mentioned minerals (Indo-German Environment Partnership, 2013). High import dependent countries tend to suffer from risks such as commodity price spikes, disruptions due to monopolistic behavior, as well as conflict and instability in exporting countries. Over-extraction and over-dependence on imports pose serious challenges for countries and thus there needs to be a focus of efficient use and productivity of resources.
2.2.3 WASTE GENERATION IN INDIA

Rapid urbanization, population growth, and changing lifestyles associated with increased consumption have led to problems with solid waste generation. In 2001, the country generated about 31.6 million tons of waste, and this amount is expected to increase five times in 2041 (Planning Commission, Government of India, 2014; Annapu, 2012). The current solid waste management system in India is ineffective. The improper handling of waste has negative impacts on public health, the environment, and the economy (Biswas, Kumar, Babu, Chakrabarti, & Bhattacharya, 2010). Development of proper waste management infrastructure preserving natural resources is essential to achieve effective economic growth (World Economic Forum, 2010). Currently 90% of solid waste is dumped in dump yards without any treatment. In place of these informal waste dumps, the country needs engineered landfills, which ideally are concerned with safe disposal of waste, protection from ground and surface water contamination, avoiding greenhouse emissions, wind-blown litter, and problems with animals and pests.

Informal waste pickers depend on waste for income by picking waste from waste bins, trucks, streets, waterways, and dumpsites. People also work in recycling plants owned by waste picker associations or cooperatives. There is a significant health risk to the people working in these unregulated industries. Proper solid waste management requires extensive involvement of the informal sector with support from research institutes, organizations, NGO’s, and the private sector. The safety of the informal workers involved in informal waste collection and recycling should be considered in formulating any solid waste management plans and policies.

2.2.4 CONSTRUCTION SECTOR

The construction sector is one of the highest consumers of resources in India and has grown at a rate of 10% over the last decade. In 2007, the industry was the second largest sector in material consumption after agriculture, and with current growth trends it is heading to be the highest material consuming sector by 2020 (Dittrich, 2015). The main materials used in construction in India are sand, stone aggregates, soil for bricks and limestone for cement. The cement industry
is one of the largest emitters of carbon dioxide emissions, contributing to 7% of the country's
emissions. The production is expected to increase 4 to 7 times by 2050 (WBCSD & IEA, 2013). The
construction industry will face serious material supply problems if the current growth trend
continues. The construction sector is most vulnerable to the market volatility as most of the typical
cost of a building arise from the material cost. Thus, emphasis is needed on resource efficiency
and alternative building materials to support the industry.

2.2.5 CRITICAL BUILDING MATERIALS IN INDIA

According to the report Material Consumption Patterns in India by GIZ (Deutsche
Gesellschaft für Internationale Zusammenarbeit), five critical building resources were identified
based on factors such as scarcity, cost, environmental impact, embodied energy, supply risk, lack
of recyclability, and conflict of use. The five materials were sand, soil, stone, limestone, and metals
such as iron and steel.

Sand in India has a high demand in construction as it is a source of silica for bricks. The
sand from the river is the most preferred choice since extraction is easy and does not require much
processing. Excessive extraction by unorganized sectors results in destruction of the existing river
systems. Soil is also an essential element for clay brick manufacturing but most of the soil comes
from the fertile agricultural lands. Excessive extraction poses a threat to the food security of the
country. Soil mining is mostly undertaken by the unorganized sector and thus mining above legal
limits is a common practice. Furthermore, brick kiln manufacturing has generated a bulk amount
of carbon dioxide with harmful gases such as carbon monoxide, sulfur dioxide, nitrogen oxides,
and suspended particulate matter (Central Pollution Control Board, 2015). Efforts are being made
to diminish the use of soil by using flyash, a byproduct of the thermal power plants. Stone is mainly
used as aggregates in concrete and as a base material for roads. The demand of it is predicted
to soar in the future as concrete is the main choice of construction for buildings, with the
government committing to build vast road networks in the country. Furthermore, the processing
of stone causes air pollution. A search for an alternative aggregate material will alleviate the gap
between future demand and supply, likewise reducing the pollution problem. Limestone is the most extracted material in India and extraction is estimated to last for 40 years. Limestone is mainly used for cement production. Extraction of limestone has negative environmental impacts on ground water contamination, dust emissions, and global warming potential. Efforts are being made to use flyash as an alternative to limestone. Steel is used in construction sector mainly for rods in reinforced concrete cement, steel beams, and columns. Though iron ore is abundant in India, it is a net importer of steel in recent years due to a dip in international prices (Kulkami, 2015). Though steel can potentially be recycled, steel production is an extremely polluting industry.

2.2.6 RETHINKING A CIRCULAR INDIAN ECONOMY

India faces new challenges in terms of resources and energy management due to its high economic growth and large population. It is necessary for the country to tackle the issues of erosion of natural capital, greenhouse gas emissions, and waste generation. A circular model of growth could help India achieve its developmental goals by involving both the formal and the informal sector. Some of the aspects of a circular economy are ingrained in habits of the people, which showcases a culture of repair and re-utilization of products and materials. Most of these activities are handled informally which provide means of livelihood for the poorer sections of the people.

According to an Ellen MacArthur Report on Circular Economy of India: Rethinking Growth for Long-Term Prosperity as the economy of the country develops, these informal recycling practices will become less attractive unless a more systematic approach is taken to include them in the value chain (Ellen MacArthur Foundation, 2016). Moreover, as India becomes connected to the global market’s linear supply chains, as practiced mostly in the developed economies, the problems of loss of resources and waste generation will be aggravated. The report identified three focus areas and provided recommendations where circular economies could have a beneficial impact. The three areas identified were food and agriculture, mobility and vehicle manufacturing, and cities and construction (Ellen MacArthur Foundation, 2016).
To meet the demand of urbanization an estimated 700-900 million square meters of commercial and residential space needs to be built every year against the backdrop of resource constraints (McKinsey Global Institute, 2010). In the construction sector, the principles of circular economy could be applied in several aspects that would be beneficial. The McKinsey report mentions the use of digital platforms to make informed decision about planning city spaces, setting up civil infrastructure, optimizing energy management in buildings, as well as sharing information to identify opportunities for flexible use that reduces the need for new spaces. Digital technologies can help entrepreneurs or leaders extract and analyze data in ways that use information and networks to create cities that are circular by design, thus eliminating the concept of waste by keeping assets at their highest utility at all times (Sukhdev, Vol, Brandt, & Yeoman, 2017). A circular economy could decouple development by withdrawing from the use of virgin resources using recycled or modular materials instead. This reduces the required resources and waste generation. Urban mining of construction waste also offers an opportunity to reduce material consumption. Use of BIM (Building Information Modelling) technology or RFID (Radio Frequency Identification) make it easier to reuse and recycle building materials by storing information such as post-use treatment and composition of the products. Innovative and alternative materials that are economically viable can have the potential to support the provision of affordable housing, thus reducing environmental impacts due to extracting and processing of building materials.

The potential of using solid waste in a closed loop as construction materials would mean a positive environmental and economic benefits. A major portion of solid waste in India is being managed informally and a case for a circular model could be made whereby waste is being used as a resource for building products. The recycling of waste is a labor-intensive service and it is important to consider the recycling effort in a formal supply chain of products used to make building materials. A collaborative and concerted effort is needed both from the formal and the informal sector in making decisions about how to utilize the resources from the waste responsibly into a building material. It would also create new employment opportunities. The safety of the
workers involved in this industry should be of paramount importance, and safety needs to be reinforced by implementing policies and regulations discouraging actions that have harmful human effects. Thus, the toxicity of the materials during production or use need to be analyzed for their material composition, and necessary protective actions must be taken to prevent any negative effects on human health or on the environment. Identification of tighter and smaller loops would require an information exchange platform where digital technologies could be useful. Tighter loops have the most environmental benefits and create local employment opportunities (Stahel, 2015). It is also important to question and criticize larger loops where waste is sent from the developed nations to developing nations such as India and China to be recycled where laws and regulation about waste are less stringent. The price is paid by people living close to the dump yards and immediate natural surroundings. The shipping of waste from developed nations to developing nations will stop unless the prospects of seeing waste as a resource is understood; this will result in realizing tighter loops of reuse both in developed and developing nations. The informal sector is one of the major stakeholders involved and an implementation of a circular loop would require active participation of the informal sector. For the purpose of research of a circular economy of building materials, the famous informal settlement in India named Dharavi is selected for investigation.
2.3 DHARAVI

2.3.1 THE EXISTING LITERATURE ON DHARAVI

Dharavi has been the subject of interest among many groups such as architects, planners, developers, industrialists, historians, non-profit organizations, and others. There is an existing set of literature that explains the formation and growth of Dharavi, various policies set up by the government for housing, and the lifestyle of the people. The policies as framed by the government in the early 1950s did not consider the voices of the people living in the slum. The involvement of various national and local organizations in recent decades has made it possible for the residents...
of the slums to influence policies that recognize the requirements of the inhabitants. Earlier policies were top down strategies meant to benefit mostly the rich industrialists. Dharavi lies on a land which is very lucrative but support from these organizations has stopped the government from bulldozing the slums and converting them into vertical high-rises (Day, 2010). Due to this constant tension of industrialists, governmental stakeholders, and slum dwellers, there exists a set of literature that criticizes the policies based on the argument that any housing scheme meant to displace and rehabilitate the people will not be sufficient since the existing living spaces are used as work spaces as well. Shifting the people to a formal high-rise building does not necessarily improve their lifestyle as high-rise towers will not be able to replicate the spatial relationships that foster the existing communities (Baweja, 2015). Criticisms have come from scholars, academics, and architects alike regarding the devastating effects upon the people if the housing policies were implemented. This concern is summarized well in a written response to the government by Jockin Arputham, founder of the National Slum Dweller’s Federation about neglecting the voices of the slum dwellers in forming their policy decisions on Dharavi (Patel & Arputham, 2007). A small part of the slum had been evicted and moved to a vertical apartment style housing complex, but it was a complete failure as it had destroyed the earning potential of the people. The vertical housing did not provide the same flexible living and work spaces as existed before. Due to lack of maintenance the apartments became yet another vertical slum.

A thriving informal economy exists in the slum born out of the entrepreneurial spirit of the people to make ends meet and in the hope for a better life. The informal economy is responsible for more than a billion-dollar economy that has caught the attention of several news media organizations and there are several articles on it. Dharavi is also responsible for a significant portion of the solid waste management of the city of Mumbai as the city does not have a formal waste management system. The informal economy along with the waste management industry out of this informal network is of interest to many scholars and entrepreneurs. The information about the informal economy helps to create the list of the material inventory that flows through Dharavi. For this research study, two kinds of material inventory have been studied, one which consists of the
existing building materials which are used to construct the existing houses, while the other consists of the solid waste materials that are being recycled or have the potential of being recycled in the slum of Dharavi.

There is a lack of detailed documentation about the materials and methods of construction of the informal houses. There is a gradual transformation and growth of the houses in the slums over time. The rate of growth is dependent upon an individual’s capacity for income generation or his/her access to any material inventory that can be used in the houses. This transformation has been studied based on the author’s visit to the slum and on secondary sources and articles, and pictures and videos of Dharavi. High quality images of the houses at the edge of Dharavi in “60 Feet Road: Bhatiya Nagar facades: Dharavi, Mumbai, Maharashtra, India” by Robert Polidori have helped to investigate the details of construction. The materials used in the makeshift houses is the same in all of the slums in Dharavi. To understand the growth, a report named Incremental about the growth of the houses published by the organization SPARC provided additional information, and parallels have been drawn from it to understand the informal house construction in Dharavi (SPARC, 2013). A general time lapse of growth of a 3 meter by 4-meter house is shown in this research study, showing the addition of different materials over time used for the incremental growth of the house (Figures 4.7 to 4.12).

2.3.2 THE CONSTRUCTION OF HOUSES IN DHARAVI

The construction materials of the houses in Dharavi are investigated through a culmination of the secondary sources and a tour of Dharavi in December 2017. Interaction with members of the organization URBZ Mumbai and SPARC have helped the present author to further analyze the details of housing as well as some of the social issues related to the dwellings. The houses are financed incrementally over decades. The walls are mostly made from corrugated metal sheets or polyethylene sheets on a framework of bamboo or wooden lumber. Some metal skins also come from the discarded metal drums which are spread out to form flat metal sheets. Bricks are
added to the dwellings as the financial conditions of the family or dwellers improve. The roofs are mostly built out of the metal or asbestos corrugated sheets. The use of these materials makes the interior temperature extremely high on sunny days. Improper overlapping or cracks in aging sheets results in water penetration in the houses during the monsoon period, a season marked by intense rains in Mumbai. As families grow, there is a need for the people to build higher for the need of space, but this vertical transformation is not an easy transformation due to the legal and social issues of the space. Since residents do not own the land, only temporary construction is possible. The construction of reinforced slabs, walls, and columns is legally forbidden as well as building a toilet inside. But these legal hurdles can be bypassed if a bribe is paid to the local law keepers, which could either be the police or the local criminal organization. Aspirations for a better life for the people of Dharavi are made possible by an informal revenue paid to the police.

When needed, or afforded, the addition of a floor is completed with the help of a local artisan of construction who uses previous construction experience and skills to build the additional floor. The addition of the floor uses metal I-beams placed on top of the load-bearing brick wall. Typically, two-by-two feet square tiles are placed between the steel, dictating the spacing of the beams. Usually two-by-two feet grey slate tiles are used and spans between the steel sections. The slate acts as the floor over which normally an inch of cement screed is applied, followed by a layer of decorative tile. All of the construction is conducted without any formal engineering skills. The addition of a floor by a family is only possible when they are financially well off enough to pay for the materials needed as well as the local construction artisan in addition to the bribe for the building permit. All of these construction processes are performed on a local basis and do not involve governmental registration or any other legal authorization from the government.

After the addition of a story, the roof on the top floor is usually composed of corrugated sheet metal instead of a more expensive concrete slab. Financing and availability of materials for housing are major problems faced in the slum. This is a problem where the recycling industry can fulfill the needs of the people by creating alternative building products that can offset or reduce the financing for the procurement of the materials. In addition, the production of alternative
building materials would also serve to generate income for the slum dwellers. The walls and the roof have immense opportunity for increased use of alternative building materials, with potential to increase thermal comfort and eliminate rainwater penetration. An alternative to the asbestos sheet for roofing needs to be explored to address health concerns, since asbestos is a proven carcinogenic material. In addition to residential structures, work sheds need improved building materials since incessant rain during the monsoon season can halt work causing a loss of daily income (Campana, 2013).

The main businesses that are documented are the pottery, leather, garment, food and recycling industries. There are other small entrepreneurs but those are not well documented. Since Dharavi is the second largest slum in the world and one of the largest in Asia, many tourists come to visit to get a glimpse of the lifestyle of the people, the hardships faced by the people, and the thriving informal economy. Social media blogs and posts about slum tourism are sources that provide glimpses of information on the slum businesses and the existing conditions. Tourism is conducted by local agencies who have established networks with the local people where a significant amount of the profits from the tourists goes back into slum educational programs. The slum dwellers are generally apprehensive about strangers delving deep inside the slum as they fear legal inspection which would lead to eviction.

There are several non-profit organizations working in Dharavi. Each of them has a different role in supporting the people of the slum. The organizations undertake research and collaborate studies of the settlement with universities worldwide. The active participation with these working organizations and the people of the slum result in publications of journals and reports shedding light on important aspects of the character of the informal settlement. In the present research study, these organizations have served as a valuable source of information on the residents of the slum, the housing conditions, and the informal economy. Most of the published reports and articles are available on the websites of these organizations. Among the NGO’s formed, SPARC, Mahila Milan, ACORN India, and National Slum Dwellers Federation deserve mention. Sometimes the planning and architecture departments of foreign universities collaborate with these non-profit
organization to conduct research into these slums and assist in development of publications and reports exposing the intricacies of the dynamics of the slum. Most of the recycling industry is based upon the manual work of segregating materials to be distributed to recycling centers both in and outside Dharavi.

Competitions in architecture schools in and outside India have been floated to propose ideas to improve the housing conditions of Dharavi. Some of the design solutions presented point to developing existing structural infrastructure of the housing conditions to build higher levels supported by a service infrastructure. Much of the existing literature on Dharavi points to the development of the roof or technologies that enables the maximum utilization of space to fulfill resident needs for life-work purposes.

The building materials selected by people having scarce resources may not be appropriate climatically or environmentally as they are choices determined by cultural, financial, and availability factors. The role of this research is to disseminate information about the scope of using available waste for building materials using low cost technology. In the book, Architecture for Rapid Change and Scarce Resources, Sinha (2012) makes the point that the appropriateness of a new building technology can be seen from three simple guidelines. The first is to understand whether the material will be culturally acceptable and the technology to work with can be made easily available locally. The second comes from the suitability of the material to fulfil the needs of the people in their context and climate. The last comes from the economic incentive for the technology as well the incentives gained in the long run when the material is recycled or dismantled (Sinha, 2012).

This literature leads to the criteria used herein as appropriate for developing alternative building materials from material reuse. The criteria for the scope of recycling the solid waste into a building technology in Dharavi should try to find solutions for the following needs:

- Empower the dwellers to build higher or to maximize the utilization of space
- Provide thermal comfort and rainwater protection
• Solid waste combined with any existing affordable material out of the available markets is considered to be the material input for the development of the building material

• Production of the material should not be energy intensive, create more pollution, or create a demand for a product which is toxic in nature.

• Production should not involve large complex commercial processes and even if a machine is needed for its production it is to be evaluated whether the local people could get access to such a machine with the help a one-time investment from the non-profit organizations

• Create an economy which benefits the people

• Improve the conditions of life by improving housing

It will be difficult to satisfy all the mentioned criteria but satisfying most of the criteria will result in the most benefit in terms of producing a circular economy that addresses social and environmental concerns.
3. RESEARCH OVERVIEW

3.1 RESEARCH AIMS

The aim of this research is to study of the potential as well as Dharavi’s obstacles to contributing to a circular economy of building materials from the waste materials available in the slum. Dharavi has a labor and service-based economy, which are the main features of a circular economy. This research investigates the scope and possibilities of recycling Dharavi’s waste stream into recycled building materials and identifies the requirements for the circular model to gain traction driven by the potential socio-economic and environmental benefits associated with a circular model. The research is about making a holistic case for Dharavi’s contribution to a circular economy of building products, and also delineating future possibilities and the next steps needed to make this transition.

3.2 RESEARCH METHODOLOGY

This research is an exploration of the establishment of a circular economy of building materials in the informal sector. The research is driven by the concerns of the present-day world including greenhouse gas emissions causing global climate change, scarcity of natural resources, improper living conditions, and waste generation. These are potent threats to the global population since the impact to developing nations will be significantly higher. Moreover, these countries are less equipped to handle cataclysmic events due to massive populations and lack of technology and resources. The concept of a circular economy presents a possible answer to tackle the associated problems mentioned, having far-reaching positive social, environmental, and economic impacts. Circular economy is a broad concept whose principles advocate a holistic view of the opportunities that exist in the existing flow of resources and information that can turn into a closed loop network, mutually benefitting various individual stakeholders in every network. The smaller the loop established, the better is the result. The smaller loops may have overlapping activities and once the smaller loops are established, the potential of the byproducts
of the loop to connect with another resource cycle can be realized, which culminates into a broader complex network of circular loops. The Caviar to Cardboard Project by Graham Wiles serves as a good example of how smaller loops turn into a complex network of a loop having positive benefits in each cycle. This example is explained in Chapter 2.

This research moves from the broader perspective of circular economy of the world to focus on the developing nation of India and how this concept relates to the informal settlement of Dharavi. This research studies the potential of Dharavi’s contribution to a circular economy of building materials from the waste that flows through the slum to be recycled. The research is divided into seven parts of which the first two parts comprise the aforementioned literature review.

The first part (part 1 of Chapter 2) introduces the general concept of a circular economy. It touches upon some of the early schools of thought of a circular economy such as cradle to cradle, bio-mimicry, and others. It highlights the main principles shared by these concepts and explains how a circular economy could benefit the global population amidst a growing global population.

The second part (part 2 of Chapter 2) narrows down on the problems faced by India as a developing nation and makes a case for the involvement of the informal sector in applying circular economy concepts to the benefit of both the informal and the formal building sector. It also introduces the slum of Dharavi and mentions the type of literature available on the slum.

The third part (Chapters 4 and 5) further narrows down on the various aspects of the informal slum of Dharavi. The slum is studied in terms of its origin, its existing culture, the living and working conditions, the construction methods and materials used, the type of businesses practiced, and the problems faced. This first part culminates in a final inventory of the main materials used to build their makeshift houses, as well as a list of the dry waste that the people recycle or reuse to earn their livelihood.

The fourth part (Chapter 6) is comprised of case studies where an alternative building technology is made from recycled or waste components. This includes an analysis of the relevancy of the alternative building products to the context of Dharavi, and also provides an
identification of the materials that have the potential to be used out of the inventory developed in the first part.

The fifth part (Chapter 7) is an analysis of the findings of the various building products made from waste highlighting the factors that are most relevant to the informal economy. These factors are developed from the previous understanding of the concept of circular economy, the slum conditions, and the case studies. It also identifies where the building products can be applied by classifying the house into seven elements: load-bearing building envelope, non-load bearing building envelope, flooring elements, openings with doors and windows, furniture, and finish materials. The drawbacks and advantages of the application of the specific materials are mentioned.

The last part (Chapter 8) is the conclusion, which highlights the main factors for consideration in the application of a circular economy.

3.3 LIMITATIONS

Collecting information about Dharavi is very difficult as researchers are usually met with resistance due to residents' fear of eviction and of losing the freedom to live, work, and practice businesses without taxes. Past surveys have been conducted in the slum by outside agencies, but they fail to represent the true nature of the slum due to limitations in the number and diversity of the groups interviewed. Little data could be found in terms of the materials. In the analysis chapter 7, the case study building materials are analyzed only in terms of the certain factors of suitability of the product, the ease of production, the potential of it to contribute to external market, and the technological knowledge available. A quantitative cost-based analysis is not done due to ambiguities of the stakeholders needed to implement the value chain of the circular loop and the cost of labor and machineries. This research provides the information needed to understand the advantages, the factors and the obstacles involved in initiating a loop as well as to point out the potential stakeholders who can contribute to the same.
4. BACKGROUND OF DHARAVI

4.1 LOCATION

Dharavi is situated at the very heart of Mumbai covering an area of 525 acres of land. It is a triangular piece of land served by railway lines on two sides and Mahim Creek with its mangroves. The suburban train stations are located at three corners of the site – the Mahim, Matunga, and the Sion. Dharavi occupies one of the prime locations of Mumbai and is of a huge interest to real estate developers and promoters as it is well connected to mass transport system and close to Chhatrapati Shivaji International Airport (Day, 2010). The other reason for its high real estate value is that it lies near the business districts of Mumbai – the old Central Business District of Mumbai and the new emerging financial center called the Bandra-Kurla Complex.

Figure 4-1. Aerial View of Dharavi (Source: DNA India)
Figure 4-2. Location of Dharavi in Mumbai (Source: A Study of Space in Mumbai's Slum Jan Nijman)
4.2 HISTORY & ORIGINS

Dharavi is a settlement that has developed organically over years without any formal planning. The growth of Dharavi could be attributed to the urbanization of India which started under the British Raj and due to the geographic location and commercial relations that Mumbai enjoys. In the 18th century it was an island with primarily mangrove swamps, which later in the middle of the 19th century was inhabited by an ethnic north-western tribe named Koli, who set up a fishing village there which was referred to as the Koliwadas (Cunha, 1900).

Figure 4-3. Map of Dharavi (Source: Partners for Urban Knowledge Action and Research, PUKAR; Dharavi.org; Kamla Raheja Vidyanidhi Institute of Architecture and Environment, KRVIA; Government of Maharashtra; Satellite imagery by GeoEye)
Mumbai lies on a peninsula bounded by the Arabian Sea to the West, Thane Creek to the east, and the Vasai and the Ulhas river in the north. In about 1900 Mumbai was confined to the southern part of the peninsula and was called the “Island City.” Mumbai started seeing an influx of population when it turned into a center of urban significance. The native town consisting of non-European residents started to grow in this southern peninsula without any planning due to mass migration from the rural areas. There was a huge disparity between British residents and the residents of the native people. As the population started to increase due to the migration of people for jobs, there grew an acute shortage of housing with basic infrastructure of water, sanitation, and drainage. In 1869 a plague developed from this populated part of the city which resulted in the death of 200,000 people in Mumbai and eight million in the rest of India. The plague led to eviction of the noxious activities of the polluting factories, and the factories moved to a place that is now called Dharavi, which was in the northern fringes of the native town. The slum started to come into existence during the 1880s because of the expulsion of the factories and residents from the city center by the colonial government (Nijman, 2010).

The character of Dharavi started to change from being a fishing village as a result of overpopulation. It deprived the Koli fisherman of their fishing and soon they turned to bootlegging liquor. Soon the Tamils from the south opened tanneries, Kumbhars from Gujarat established their potter’s colony, and people from Uttar Pradesh migrated to form the textile industry (Jacobson, 2007). Until 1956 Dharavi was outside the city limits of Mumbai but as Mumbai expanded northwards the city grew around Dharavi, and in the 1970s it occupied almost the middle of the city. Since the 1980s the government came up with various schemes for redevelopment where some infrastructure and amenities were provided. Some houses were built with the help of the government, but these projects did not have much impact on the nature of the slum.

4.3 EXISTING BUILDING CONDITIONS

The existing slum covers an area of 525 acres. The exact boundaries and topographies are extremely difficult to map. The exact population of the slum is unknown, but it is estimated to be
around 1 million people. At present, it has 85 neighborhoods with each of them having a distinct character based on religious, ethnic, and livelihood identity. The population density in Dharavi estimated to be in the range of 270,000–450,000 inhabitants per square km which is approximately 35 times the population density of New York City, all cramped in an area equivalent to two-thirds of the area of Central Park in Manhattan. The slum is organized in a complex labyrinthine physical layout built around work-life dwelling spaces (Boano, William, & Newton, 2013). It has around 15,000 single room factories employing around a quarter million people housed in single room tenements. Spaces are multifunctional, and flexibility is a key to their living. During the day, the ground floor is used for small businesses and shops while during night some workers may sleep in them with the family members in the upper stories. Dharavi’s building stock is a combination of permanent and impermanent structures displaying originality and innovation in the use of the construction waste. The median floor areas are typically 10 square meters with each unit housing having an average of five to six people (Baweja, 2015). There are no formal living areas. There is no sanitation infrastructure for most of the people and sometimes people have to buy water from the water sellers for their use. There is only one public toilet per approximately 1500 residents. The space for a private bath is a dream for many and some of them uses the kitchen space as a bath area. Most of the rooms have a cooking gas stove and access to electricity. Some of them have a color television with cable connection with even some having a video player (BBC News, n.d.).
Desiring a better life has led to an entrepreneurial spirit causing growth of a diverse range of entrepreneurs and local businesses such as pottery, garment production, food, and recycling. As businesses turn profitable, the money is spent on educating their children and improving their homes. (The Huffington Post, 2011).

The houses of Dharavi range in quality. They range from temporary shanties made out of bamboo, wooden sticks, and corrugated metal sheets, to houses made of more permanent materials such as brick, mortar, and concrete. The range of materials for housing used are bricks, wood, concrete, rusted iron, steel I-section beams; ceramic, slate and clay tiles; asbestos sheet; and tarpaulin sheets. There are incremental additions or alterations to the houses as time goes by. As the dwellers economic situation improves over time, the nature of the construction of the house phases from a temporary to a more permanent construction. Initially the houses start on normal ground with bamboo or wooden sticks embedded into the earth which forms the frame on which the tin sheets are placed to act as a wall. The tin sheets or asbestos sheets are also used as the
roofing material. The thin metal sheets have poor heat resistivity and create extremely hot indoor temperatures during the day. Moreover, due to improper overlapping of the tin sheets and due to perforations of the tin sheets because of rusting, water penetrates through roof and walls. To counter the effects of water penetration, the dwellers use blue tarpaulin sheets or other available plastic sheets to cover up the roof. The asbestos sheet does provide protection from the thermal heat, but it is a known carcinogenic material. If the family in due time can perform well financially, the tin walls gets replaced with brick and mortar walls. This transformation of the walls is gradual where one wall may be replaced in one year while the other walls are replaced gradually in the subsequent years. The replacement is dependent upon the availability of the resources at hand. As the family grows the need for more spaces requires them to build higher. Sometimes people build the higher stories just to rent the space for other families to move in or to be used as working spaces. The upper floor construction is commonly made with a framing structure of steel I-beams, which usually spans one-way three to four meters between the walls. Natural grey slate tiles are used as a decking material over which cement screed and tiles are applied to form the floor. The natural tiles are usually available in 2 feet by 2 feet size. The spacing of the steel beams is dependent upon the size of the tiles. The roofing structure is either wooden sticks or I-beams. Sometimes trusses are formed for longer spans. (Dovey & Tomlinson, Dharavi: Informal Settlements & Slum Upgrading, 2012)

The access to the upper stories are accomplished by using a metal or a wooden ladder from a common street. This placement of staircases ensures maximum utilization of space in upper stories. The stairs are connected to the main street. Most of the windows in the houses do not use glass panes. They have a grill box projecting out of the outer wall which provides them with extra space for keeping house hold items. Flexibility of working and living space is maximized using lofts, stackable mattresses, and folding tables. The upgrading process of the houses is undertaken by a local contractor, who is usually well connected with the local municipal officers, and who lives there being aware of the flexibility and restrictions of every rule. Contractors' training background begins at a very young age by working on small construction sites (sP+a & URBZ, 2015).
Concrete is a building material that provides a minimal level of comfort from heat and better protection from rain in the rainy season. Since April 2012 LafargeHolcim, an international building material manufacturer, has taken up the task of delivering concrete to the heart of the city by using motorized rickshaws carrying 15 liters of slow setting concrete as trucks are inaccessible inside the slums. Some of the inhabitants could add an additional story to their due to the stability of the concrete slabs. The only problem with the formal construction of slab building is that it is capital intensive and only a certain wealthy section could afford it. Most of the roof at the top story of these houses is not a concrete slab as is evident by an aerial photograph of the slum, but a makeshift solution of using corrugated tins or asbestos sheet is used for roofing.

Figure 4-5. Pictures Showing Cantilevered Construction

Source: Dharavi: Informal Settlements & Slum Upgrading by Melbourne School of Design
According to the literature, the construction of the slum houses is elaborated in the figures (4.7 to 4.12). They highlight the method of construction and the type of materials used. The different stages (Stage 01 to Stage 06) in the figures showcases the vertical growth of the slum house over time by the addition of more materials.
Figure 4-7. Schematic Sketch of the Construction of a Slum House Stage 01 (Source: Sourav Dey)

Figure 4-8. Schematic Sketch of the Construction of a Slum House Stage 02 (Source: Sourav Dey)
Figure 4-9. Schematic Sketch of the Construction of a Slum House Stage 03 (Source: Sourav Dey)

Figure 4-10. Schematic Sketch of the Construction of a Slum House Stage 04 (Source: Sourav Dey)
Figure 4-11. Schematic Sketch of the Construction of a Slum House Stage 05 (Source: Sourav Dey)
Figure 4-12. Schematic Sketch of the Construction of a Slum House Stage 06 (Source: Sourav Dey)
4.4 ENTREPRENEURSHIP CULTURE

Dharavi is integral to Mumbai’s economy. The retail, manufacturing, recycling, and wholesale supply chains operating out in Dharavi is estimated to turn in over a $US 660 million to a billion annually (Yardley, 2013). The houses are of a multi-user type – residential and commercial. Most of the production and manufacturing in the slum are not registered. The industries in the slum consist of tanneries, pottery, textiles and tailoring, gold and jewelry, surgical thread, steel fabrication, and kite manufacturing units along with other manufacturing units that deal with a variety of food items such as aspapad, chikki (a sweet made from peanuts and jaggery), and snacks.
Dharavi is unique in terms of its close work-place relationship. Innovation and ingenuity is the residents’ weapon to battle against poverty. Dharavi’s industrialists enjoy the competitive advantage of cheap labor and an environment where government inspectors fear to tread into. It is a thriving business center with thousands of micro-entrepreneurs who have also created an invaluable industry of recycling. Economic activities are often linked with ethnic identities in the neighborhoods formed, as most of the tanners are from Tamilians and are Muslims, while embroidery works are done by people from Uttar Pradesh, and the pottery is produced mostly by people from Gujarat. Home based entrepreneurship is an essential element of the informal economy (Nijman, 2010).

4.4.1 POTTER INDUSTRY

The potter industry in Dharavi is one of the oldest and the potters have their own separate colony known as the Kumbhawarda. It covers an area of 13 acres and it is home to 5,000 potter families. Most of the people are 6th or 7th generation potters from Gujarat (Kapadia & Rovshen, 2014). The character of the spaces in Kumbhawarda is different from the rest of the slum. Unlike the rest of the slum, this potter colony is relatively clean, well-ventilated and has more open space. Spatially the potter industries either open into a yard or into the street. The makeshift kiln is placed in the yard, while the finished items are displayed and sold in the street (Day, 2010). The entire area is again divided into four areas, and each area is specialized in making certain kinds of pottery items such as planter pots, water pots, bowls, and lamps of various shapes and sizes. The industry is based upon a seasonal demand. Religious festivals such as Diwali and Makar Sankranti contribute towards creating a demand for these pottery items. There are potters who make around 25,000 to 30,000 pots per year. Potters here in Kumbhawarda are much financially better off than the rest of the people in Dharavi.

The clay comes from a place called Thane in Gujarat and the potters buy it from the local suppliers, but it is a growing concern that Thane is running out of clay as most of the land for clay extraction is used up for construction. They also get local clay from Maharashtra. The clay is first
melted in a pit and then kneaded with feet in the open spaces available there. Then they are wedged by hand to make a uniform clay. Finally, the various shapes are made by hand in rotators. The productivity depends upon the machines and molds they have. Many have started to use electric rotating motors instead of the manual wheel ones which helps them to make their production faster. The products are then burnt in traditional brick kilns fired up by waste cotton, saw dust, oil-based pharmaceutical waste, and waste cardboard, which is responsible for a lot of smoke. These kilns create a higher proportion of damaged pots when compared to electric kilns. Aluminum sheet is put on top of the traditional kiln for cover (Kapadia & Rovshen, 2014).

Gas furnaces are used by some potters for baking to manufacture better quality products. The advantages with these kinds of furnaces is that they do not produce any smoke, produces less damaged products, and the temperature for baking can be controlled. A traditional brick kiln accounts for at least 30% rejection due to breakdown of the pottery products.

Figure 4-14. Pottery Unit in Dharavi (Source: Wikimedia Commons)
4.4.2 LEATHER INDUSTRY

The leather businesses in Dharavi are remnants of the old flourishing leather industry that dominated the area during the 1950s and 1960s. Due to its toxicity, most of the larger tanneries were relocated out of Dharavi to a place called Deonar, a suburb in Mumbai. Despite an official ban some of them still function today. There are lanes in Dharavi which are used for drying the wool from the sheep and goat skins in the sun. At present only the first and the last stages of the leather processing is being handled in Dharavi. The raw hides arrive from the abattoirs in the night where the hides are treated with sodium sulphide and left for around four hours. The stench of the warehouses dealing with this kind of activities is intense. The semi-processed hides are shipped off to Chennai or Deonar for final processing. The processed hides return where they are crafted into finished leather products by the workers in overcrowded lofts or workshops (Sharma, 2000). The finished products consist of bags, wallets, slippers, and shoes. Some of the workshops make the shoes without soles and send them to a factory that deals specifically with adding the soles. The finished products are then exported to Australia and Japan. There is variety amongst the leather industries and each product is dealt with differently depending upon the workshops and the end users. There are success stories of people earning over one crore Indian rupees annually by dealing with just footwear exports.

4.4.3 FOOD AND MEDICAL INDUSTRY

Dharavi has a unique and complex network of distribution of collection and delivery of more than 200,000 tin lunch boxes to office workers all around the city of Mumbai and again returning them back to their source. The business has its origin in 1880 during the British rule where British people wanted home-cooked food delivered to their office tables. This service-based business is extremely efficient, and it is estimated to have only one mistake in every 16,000,000 deliveries (Sharma, 2000). There is a flourishing food making industry in the slum that produces
sweets, snacks, biscuits, and various types of breads and buns. People in Dharavi come from all parts of India and they prepare food that is usually the specialty in their local regions.

There is also a suture factory in Dharavi, and its proximity to the abattoir has made possible the growth of the industry. It is setup by Abdul Baqua who came from the state of Uttar Pradesh. He was trained in the suture trade in a Coimbatore factory but later he partnered with an Italian exporter to form Ideal Trading Company with a factory in Dharavi. His factory is WHO certified amidst the unhygienic spaces of Dharavi. The factory maintains the highest standards of hygiene meant for export (Day, 2010).

Figure 4-15. Abdul Baqua at His Suture Making Factory (Source: Rana Chakraborty)

4.4.4 GARMENT INDUSTRY

The garment industry flourished here as many leather processing industries were banned and got shifted out of the slum. There are over 3,000 small scale garment factories operating. Most of the garment industry cater to the local market, but some warehouses export to distant markets such as the US where they are sold through Wal-Mart and Kmart. The working conditions are
extremely poor. Most of the workers work in poorly ventilated heated rooms with low ceilings. Workshops usually consist of long tables with sewing machines. Workers produce around 500 shirts each day and are paid on a piece rate basis. They tend to work 10-13 hours a day. However, there are some rags to riches stories that float around the industry, and they are a sort of motivation for the workers. The majority of the workers are exploited with scant pay. Embroidery works require most skill and are usually done by young people from UP, Bengal, and Bihar. Bales of cloth arrive from mills to Dharavi workshops and are stored in the corner of the workshop. The smaller workshops are normally set up in upper floors and are rented by people living on the ground floor.
4.5 ISSUE OF HOUSING AND STATE INTERVENTIONS

The Municipal Corporation of Greater Mumbai owns approximately 77 percent of the land in Dharavi, while the rest is held by other government and private parties. After India’s Independence in 1947 the governmental approach to the slums involved a harsh policy of clearance and demolition without any consideration for families living there. (Boano, et al., n.d.). The attitude of the government changed from the policy of eviction to look for a solution to address the problem of slums by introducing the Maharashtra Slum Areas Improvement, Clearance and Redevelopment Act of 1971. It was an improvement in the sense that it had the ideals of providing the people in the slums with some dwelling spaces after clearing them of their original dwelling shacks. The Slum Improvement Programme of 1972 followed this objective and aimed to provide basic civic amenities such as water, electricity, latrines, and sewage, but it was a failure in its implementation due to the lack of a comprehensive centralized plan and lack of maintenance policies. The schemes were the first steps in recognizing the rights of the slum’s residents to occupy private lands. Later in 1976 surveys were carried out. A section of the people was provided with photo identities along with the introduction of a certain tax scheme of a minor fee of twenty-five rupees, which many people were confused concerning whether it was for rent.
or ground tax (Chatterji, 2005). This enabled the people to stake some claims on the land. Later in 1980, a new scheme of the Slum Upgradation Programme aided by the World Bank was put into place. The scheme put more emphasis on the formation of housing co-operatives rather than tending to each individual need. The scheme started by giving tenure rights to the co-operatives and access to basic amenities such as water and electricity. However, the scheme prevented rebuilding regular apartments with reinforced concrete structures but allowed upgradation with plaster and brick in place of tin, mat and plastic sheeting. This was again a failure as it was very difficult to form the housing co-operatives due to complex administrative processes of registration and ambiguity of the nature of land ownership (Chatterji, 2005). At the end, only 200 co-operatives were formed instead of the estimated 1,000 housing societies.

The next phase for redevelopment in Dharavi came with the Prime Minister’s Grant Project sanctioned by the then Prime Minister, Rajiv Gandhi in 1985. It allocated 300 million Indian rupees just for Dharavi. It considered making residential structures in a systematic manner considering the economic centers of the slums. Again, this failed to implement its conceived plan as it did not properly consider the fact of high spatial density in the interior of the slums. In 1995, the Slum Rehabilitation Act (SRA) was formed which recognized the rights of the slum dwellers only if they could provide proof of residence before 1995. The issue with these proofs of residence is that the slum dwellers do not feel secure having an identity as this means they might need to provide taxes for residency as well as their businesses.

During the 1990s as India’s market liberalized, the state withdrew from its former responsibilities of providing housing for poor. The government of Mumbai aimed for a slum free Mumbai and had the vision of transforming Mumbai into a world class city along the lines of Singapore and Shanghai. The idea was floated by the report titled Vision Mumbai: Transforming Mumbai into a World-Class City: A Summary of Recommendations by the McKinsey Consulting and Bombay First in 2003. (McKinsey & Company, 2003). The report proposed incentivized models of urban renewal and rebuilding the city with higher FSI (Floor Space Index) of 3-4 instead of the current models of FSI of 1.0, 1.33, and 2.5. The concept of rebuilding was based on a public-private
alliance that would attract global capital in the form of foreign direct investment (FDI) into the housing sector. This meant demolishing the existing building stock and rebuilding it with higher FSI and generating profits through sale of the surplus built area (Baweja, 2015).

The Dharavi Redevelopment Project (DRP) in 2004 was based upon this model of incentive FSI, where surplus FSI is used for low-income housing and infrastructure on site. It was developed by architect Mukesh Mehta. The area was divided into five sectors and each area was bid out for development by five private developers. The DRP envisioned transformation of the place from the low-rise style to a high-rise typology without any consideration for the diversity of different neighborhoods in the place. Under the DRP anyone who can prove their residence from or before 1 January 2000 were eligible for a permanent accommodation without any cost. Only one-fourth of the population were found to benefit under this scheme. Eligible people were guaranteed a 225 square-foot apartment (Chatterji, 2005). FSI of 2.5 were allowed for slum rehabilitation projects all over Mumbai, and the program needed an approval of at least 70 percent of the slum dwellers. In the case for Dharavi Redevelopment Programme, the government deregulated the FSI to a higher value of 4 and exempted from the 70 percent consent rule.

The residents of Dharavi were never consulted in the formulation of their plan. Surveys to implement the Dharavi Redevelopment Programme were incomplete due to extremely dense and fluid patterns of settlement. At present the role of the NGO’s is now being formally recognized by the government in the recent projects and they are instrumental in improving awareness amongst slum dwellers, involving the residents, and affecting policy implementation. There are more than 100 NGOs in Mumbai which are aimed at helping the dwellers to press their rights regarding housing. Some of the high-profile NGO’s are SPARC (Society for the Promotion of Area Resource Centers), YUVA (Youth for Unity and Voluntary Action), Mahila Milan, and NSDF. Their efforts have stopped the land grab scheme.
4.6 THE INCREMENTAL DEVELOPMENT APPROACH

The current methods and practices of the government in solving the issue of housing for the slum people is not sustainable. It is mainly a profit scheme that caters to rich investors or developers. Any outside organization involved in redeveloping Dharavi will try to maximize space for units to be sold to outsiders and minimize the space and cost of accommodating Dharavi’s residents. The people of the slum are not primary beneficiaries of any of the schemes proposed, and that is why they have always been neglected. The top-down approach of having a slum-free Mumbai will destroy the livelihoods and lifestyles of these people. It will destroy the economic connections it has had with the formal city where both parties benefitted. The street and the lane networks are an important aspect of their lives as domestic production often spills into public space. The interconnectivity of streets and livelihood will be destroyed by formalization. In the case of Dharavi, land tenure is ambiguous. The houses are mostly self-built and owned by residents who later become landowners. Many residents own up to four rooms out of which some are rented for housing or industries. Plan for wholesale formalization meet stiff resistance because they entail a loss of jobs, convert homeowners into tenants, and leave former tenants homeless (Dovey, Informalising Architecture: The Challenge of Informal Settlements, 2013). High levels of informality enable micro-flows of information, goods, materials, and practices that enable them to generate income for their sustenance. The practices are integrated with micro-spatial adaptations that flourish under conditions of informal urbanism. Mumbai has no formal waste management plan, and thus the other grave consequence of removing the people of Dharavi from the existing framework would be that the estimated 7000-10,000 tons of waste generated every day in Mumbai will end up in landfills. Though the recycling helps to keep the waste out of the slum, it is important to remember that this comes at a price where the health of the individuals is affected. Daily exposure to some of the toxic waste materials puts a toll on life expectancy of the people. An awareness campaign run by the NGOs involved in Dharavi might help them to achieve better ways to handle the waste using proper masks and gloves.
Upgrading the people of Dharavi to a private space in tall apartments is not sustainable as it moves them away from their network of employment. A drastic shift of one million slum dwellers to the formal housing would require the residents spending resources comparable to the middle and upper-class society. It is not a very effective solution and cannot be expected of the people. Houses in the slums are made of mostly recycled materials with low embodied energy and follow a pattern of incremental upgradation depending upon the monetary resources acquired over time or on the availability from waste materials that can be utilized for improving their homes. The issues of slum housing have been a concern among many people including architects. The pragmatic solutions to the issues have always depended upon an incremental approach in which the formal design element is an infrastructure that serves to ease the informal building process using less resources (Alcamo, Bosco, & Federighi, n.d.). Many proposals for urban architecture in Dharavi attempt to draw focus on roofs as they hold the potential for maximizing the available space vertically.
Figure 4-20. Picture Showing the Interior of a Work Shed that Reveals the Structural Wooden Lumber Used to Support the House and the Ladder Going to the Upper Floor (Source: John Minchillo)
5. THE CULTURE OF RECYCLING

5.1 WASTE FLOWS IN DHARAVI

In Dharavi there is an estimated 1,200 units of waste recycling out of which 780 are plastic recycling (Pandey & Sharma, 2014). The opportunities for innovation and utilization of these available waste resources combined with an initiation of entrepreneurial activities through the recycling industry is the aim of the present research study. The existing economy, though it exhibits features of circular economy, is not circular in the true sense as some of the industries are polluting and recycling is done at the cost of the health of the persons involved.

Dharavi is known for its recycling. The estimate is that it recycles about 80% of Mumbai’s dry waste discarded by the city having a population of 19 million citizens. In the recycling shacks, people sit in waist deep piles of car batteries, computer parts, fluorescent lights, plastic bags, paper, cardboard boxes, and wire hangers. Each item is sorted for recycling. There are workshops which have aluminum smelters recycling drink cans. People stir huge vats of waste soap retrieved from rubbish tips and local hotels. One-gallon size oil cans are cleaned and hammered back into shape. Then they are sold back to the oil companies and local consumers (McDougall, 2007). The 13th compound is a compound where most of the recycling and scrap industry is concentrated, focusing on cotton scrap, iron scrap, glass products, empty tins, empty bottles, all sorts of plastic ranging from drums to bags. Recycling of the big blue plastic drums which are used for storage purposes is a big industry here. The different types of waste according to materials is mentioned below.
5.1.1 PLASTIC RECYCLING

The plastic recycling industry is a major recycling industry in Dharavi. Piles of waist height plastic are being sorted by people in tiny warehouses according to color, density, and grade (resin identification code). They know how to segregate and sort them out depending upon the type of the plastic used. Years of experience in this manual sorting industry have led them to this understanding. Usually there is a systematic procedure that helps to identify the different kinds of plastic waste and usually consists of three steps. First is to locate the resin identification code, and those which lack a code are moved to the second step, which is to correlate the product with the most likely material. Sometimes immersing the plastic in saltwater in drums helps to segregate
heavy and light pieces. The plastic items identified from the pictures, videos, and other literary sources consist of broken toys, pens, bottles and car bumpers. Plastic products which are used frequently, and which are available in plenty are in good demand as it is a steady supply of products which they are familiar with and know where to send them. Plastic from automobiles is a steady source because each car has a good amount of high grade plastic in them. The car bumpers and dashboards are being cut to smaller pieces to put into a shredding process. The plastic arrives by truck in huge sacks sourced from around the world and comprises salvaged water bottles, plastic cutlery, hospital waste, cruise ship waste, spent plastic bags, and synthetic fiber clothing (Weisman, 2013). Multinational companies send their large blue plastic drums for repair and those which can be repaired are fixed by the workers who get paid a small amount for their work. The damaged ones are sent to the recycling centers where they are shredded. Chemical compounds may still be there in the drums and the workers dealing with it are unaware of the toxins they are exposed to (Sharma, 2000). The capacity of drums which are about 4 feet is about 200 liters. Many the slum dwellers have one of these plastic drums in their houses or in front of their houses if they do not have the space to keep it inside. As water supply is irregular, some of the drums are used to store water that could serve a family of five people up to five days (Fernando, 2014).
5.1.2 GLASS RECYCLING

Glass in Dharavi is collected from various parts of Mumbai by ragpickers and consists of liquor bottles, surgical vials, ketchup and sauce bottles, jam bottles, and small medicinal bottles. Glass is a material that can be recycled many times without any loss of quality and it requires less energy to process the recycled glass into secondary glass items, but this is not the case for the microwaveable glass items such as Pyrex which cannot be recycled due to its resistance to high temperatures. The glass is cleaned and sorted according to colors as quality of recycled glass item depends upon the purity of similar types of material. The metal caps and corks are separated from glass items manually. The glass items which are in good condition are re-sent to factories for
re-packaging, while the remaining items are broken into shards that are later melted in the factories to be made into new glass products (Dharavi Biennale, 2015). The sorted-out glass items are sent to merchants who buy it from the slum residents, the cost being set according to the weight and the quality of the glass sold. The exchange price depends upon the glass materials. The colored bottles fetch lower prices than the clear ones.

Figure 5-3- Glass Recycling in Dharavi (Source: Dharavi Biennale)

5.1.3 E-WASTE RECYCLING

India produced about 8 hundred thousand tons of e-waste in 2012 and this e-waste production is growing at an alarming rate of 10%. Mumbai is the largest e-waste generating city in India followed by Bangalore, Chennai, and Calcutta. 70% of the electronic waste comes from the government, public, and industrial sectors, while the rest are being contributed by the manufacturers. Out of the total volume of e-waste, television sets contribute to 68%, desktops and servers 27%, imports 2% and mobile phones 1%. Only 23 units are currently registered with the Government of India, Ministry of Environment and Forest, Central Pollution Board, but most of the recycling process still exists in the unorganized sector (Das, 2014).
Dharavi is home to one of the largest electronic waste recycling hubs in India managing the electronic waste of Mumbai. Discarded mobile phones, old modems, cassettes, chargers, computer spare parts, monitors, keyboards, printers, ink cartridges, and tangled wires are some of the e-waste found amidst the waste piles. The recycling workshops get their e-waste from waste pickers known as kabadiwallahs who scour the city of Mumbai for materials that can be reused. Piles of e-waste in gunny bags can be seen to occupy the workshops from floor to ceiling. They come in trucks and unloading is done at the lane which links to the Dharavi’s main road. Workers working in this industry follow crude methods of recycling without any safety gear and are exposed to harmful toxins from old equipment.

Toxins such as lead, lead-oxide, and cadmium are present in cathode ray tubes and printed circuit boards, batteries; mercury is found in switches and flat screen monitors; and brominated flame-retardant compounds are present in the electronics (Sohrabji, 2010). Some of these harmful compounds which are banned in the developed nations are still in use in electronics in developing nations such as India due to lack of strict rules. Thus, they pose a risk to the health of the recyclers. Lead can cause brain damage, and mercury in very low doses can cause brain and kidney damage, while brominated flame retardants cause hormonal dysfunction. Nitric acid is used on the circuit board to remove gold and platinum. After extraction of metal from the circuit boards the remaining boards which cannot be recycled by crude methods are burnt, which releases brominated flame retardants in the air. The extracted copper and plastic is sold to metal and plastic processing factories that produce items such as PVC pipes and cables. Some methods of extracting include identification of the parts where the metals such as gold or platinum are concentrated on the printed circuit board and breaking them into smaller parts in Dharavi. Once e-waste is segregated in the working sheds of Dharavi it is sold to the traders who have liaisons with bigger companies where they sell their product.
5.1.4 METAL RECYCLING

The aluminum items are sorted by rag pickers in Dharavi and sold to merchants who bring them to aluminum recycling operations. Drink cans are good sources of aluminum. The items are broken down into shards and smelted into ingots to be sold into bigger aluminum companies that deal with products made from metal. The shards are made with help of machines that shred the items. The smelting of ingots is done with help of a make shift furnace which is basically a fiery hole in the ground. (Faherty, 2015). The melting is done at high temperatures of 600° C to 660° C, which makes the room extremely hot. Ventilation in the work sheds is assisted by fans. The scrap metal from the electronic waste items are used for industrial purposes.

A recycling shed named Kohinoor Dye-Casting has been manufacturing aluminum alloys for the last 40 years and recycles a volume of over 50 tons every month from e-waste such as discarded air-conditioners, electrical wires, computers, or fan (Jamwal, 2014). Metals such as
copper sourced from circuit boards and wires fetch more money per kilo weight than for one kilo weight of plastic.

Chemical tin cans are being sent to Dharavi for recycling. The cans have chemical remains and some of them might be toxic in nature. The workers first burn all the chemical cans to get rid of the harmful chemicals creating toxic fumes. The burnt tin cans are then washed to wear off the soot in the tin cans. If the cans are distorted, they are hammered to get back into better shape. Finally, the cans are painted and polished to give a new look. According to workers the process of recycling can be continued three times for each can as the material gets thin after each burn. After the third use, the tin cans are cut open into a long rectangular sheet. The sheet is then used as a building skin hammered by pins to the wooden framework of the houses.

Figure 5-5. Recycling of Metal Cans 01 (Source: www.blog.shunya.net)
Figure 5-6. Recycling of Chemical Cans (Source: Global Citizen)

Figure 5-7. Recycled Aluminum Bricks (Source: msolearytravels)
5.1.5 CARDBOARD AND PAPER RECYCLING

Some workshops have a floor of cardboard strips which are hacked from salvaged boxes. They are scooped by laborers who produce smaller boxes from them. They are sold to stationery and packing companies, while some are usually sent to various paper recycling industries where they are turned into pulp to make folders and furniture (Chu, 2008). Mainly, people from Dharavi are involved in collection of paper and cardboard. Similarly, to the plastic industry, they are sorted according to characteristics of paper or cardboard and stored in warehouses in Dharavi to be sent to the recycle centers. Papers and cardboards of poor quality that cannot be recycled are shredded to form fuel for various incinerators in the Dharavi workshops - examples being the pottery and the aluminum smelting workshops.

Figure 5-8- A Man Carrying Cardboard Sheets (Source: Benito Fernando)

5.1.6 TETRA PAK RECYCLING

Compared to the amount of plastic recycled in Dharavi, the amount of Tetra Pak that comes into Dharavi is much less as recycling options are limited in the case of this material and
thus recyclers would not get much price reselling it. Currently ways of reusing and recycling Tetra Paks have been found which initiated a Mumbai NGO named “Are you Reducing, Reusing and Recycling?” (RUR) to start an awareness campaign named “Go Green with Tetra Pak” in 2010. The campaign was done in association with the Swedish Tetra-Pak Association collaborating with Indian companies such as Reliance Fresh and a grocery store named Saharkar Bhandar. It aimed to educate the consumers to responsibly dispose Tetra Pak cartons in desired collection bins. From 2010 to 2015 the campaign had collected over 1,500,000 used cartons. They were recycled into 140 school desks for less privileged schools and 50 benches in community gardens (Tetra Pak Association, 2015). The other recycled products made were roofing sheets and notebooks. It takes about 6,000 tetra pak cartons to make 1 roofing sheet and 4,500 cartons to make 1 school desk (Chatterjee, 2017). The value of Tetra Pak recycling has been realized recently in the past few years, and that is why until now the volume of Tetra Pak flowing into Dharavi from the rag pickers is less compared to the volume of plastic coming in. However, due to its potential for recycling and the emergence of the Tetra Pak recycling centers, it is important to recognize the product of the Tetra Pak carton as a potential material in the search for a circular economy of building materials in Dharavi.
<table>
<thead>
<tr>
<th>GLASS</th>
<th>PLASTICS</th>
<th>PAPER &amp; CARDBOARDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquor, medicinal and soda bottles are the major contributors of the source of glass. The bottles varying in sizes and colors are segregated and sent to the recycling centers.</td>
<td>Plastic recycling is the major recycling industry where bottles, cans and containers of different grades of plastic are separated, washed and sent to the grinders to be transformed into plastic pellets. The plastic pellets are supplied to the industries outside Dharavi for manufacturing</td>
<td>Used cardboard boxes are reprocessed to be used as container boxes. Interior boxes are spiked up and sold to local businesses for their pulp to be recycled into items like brown paper. Throw away books, newspapers and magazines are sorted and sent to industries to be recycled into new paper or to be used as fuel for incinerators.</td>
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<tr>
<th>E- WASTE</th>
<th>METAL</th>
<th>TETRA-PAKS</th>
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<tbody>
<tr>
<td>Parts of discarded computers, cell phones, tablets, washing machines, fridges, air-conditioners, and other items are dismantled. The plastics and the raw metal are segregated and sold to local metal smelter or plastic manufacturing plants. The parts that cannot be recycled go to the landfill.</td>
<td>Metal inventory consists of tin oil cans, deaerant bottles, copper wire, metal wire hangers, kitchen utensils and beverage cans (mainly aluminium). All of these materials are recycled in some way or the other.</td>
<td>Though there is far less evidence of recycling tetrapaks from Dharavi its potential as one of the waste material inventory cannot be ignored as environmental groups through initiatives like “Go Green with Tetra Pak Recycling” have demonstrated the recycling potential of it by collecting over 6 lakh cartons from Mumbai houses since its inception in 2010.</td>
</tr>
</tbody>
</table>

Figure 5-9: Existing Recycling Industries (Source: Sourav Dey)
6. CASE STUDIES OF BUILDING FROM WASTE

6.1 INTRODUCTION

The previous chapters helped to explain the type of waste inventory that flows through the slum of Dharavi and the level of technological sophistication that exists. This helps to identify the type of contribution that the people of Dharavi can add to reinforce a circular economy of building materials from the available waste. This chapter looks at various case studies of building materials from around the world experimented from waste whose first use was not a building product and those types of wastes which are available in the slum. Seven types of waste from which building materials have been made are identified and studied. They are:

01) Plastic
02) Cardboard
03) Glass
04) Paper
05) Leather
06) Tetra-Pak
07) E-waste

The list of seven comes from the list of the recycling industries available in Dharavi. The leather industries in Dharavi are wasteful and thus their potential to produce waste-based building materials is considered and included in the list. The list does not include scrap metal as a potential waste due to the lack of evidence of it being recycled into a building product whose first use was not a building product. The case studies of building materials from these seven types of materials mentioned previously have been studied. This research tries to gather information about the production processes of these materials, the material properties, the obstacles of recycling, and challenges involved. This also discusses the suitability of the building products to the context of Dharavi.
6.2 BUILDING MATERIALS FROM PLASTIC RECYCLING

6.2.1 PLASTIC LUMBER

6.2.1.a INTRODUCTION

Plastic lumber has been developed and sold by many companies. HDPE plastics form the major ingredient of the recycled product. Companies such as Bear Board, PlasTEAK, Marktaar, Bedford and others sell lumber made from recycled plastic, and this plastic lumber is mainly used in decking, railings, and furniture. The advantages of plastic lumber over wood lumber is that it does not rot or become affected by termites. The use of plastic lumber prevents deforestation and can be recycled again at the end of their original intended use. Thomas Nosker, a professor in the Rutgers University-New Brunswick from the Department of Material Science and Engineering, developed a stronger plastic lumber from recycled plastic bottles, coffee cups, and other plastics which could be used to span bridges strong enough to support 120-ton locomotives. 1.5 million railway ties in the United States have been built using this technology. Fire retardants and machines for plastic lumber production have also been researched and developed. Recycled HDPE planks were developed earlier, but they showed the problems of sagging over time when load was applied. Polystyrene was later added with HDPE, which helped the material to gain strength. Apart from the durability advantage of plastic lumber over wood, wood is sometimes treated with toxic preservatives which could leach into soil and groundwater, while the structural plastic lumber does not pose such risks as it is mostly made out of High Density Polyethylene reinforced with stiffer plastics or recycled composites such as car bumpers (Blesch & Bates, 2016).

6.2.1.b APPLICABILITY IN DHARAVI

In Dharavi the plastic lumber would be very useful as an alternative to the steel I-beams used for the construction of the floor of the first floor. The plastic beams developed are strong and lighter than steel, and thus plastic beams prove advantageous in terms of construction as well as
load applied on the load bearing walls. Lighter and stronger materials mean residents can build higher due to causing less stress on the load bearing walls. Moreover, the houses are constructed manually with the help of local labor and thus lighter materials will be easier to transport as well as to handle during the process of construction.

6.2.1.c CONCLUSION

Research is needed to identify which type of waste commercial plastic products available in Dharavi will be useful to create plastic beams that are structurally sound to function as an alternative to the steel I-beams. In India, the low-value mixed plastics such as the thin polybags, pouches, pen refills, cups, trays, and other products finds their way to landfills due to their low economic value of low weight to volume ratio. Recycled Plastic Lumber is an initiative taken by several companies such as New Plastomers India Ltd, PlastWud, Shakti Plastic Industries & Deluxe Recycling India Private Limited, which manufacture the wood-like lumber from mixed plastic waste. The product has a wide range of applications such as piers, decking, flooring, roofing, loading/unloading docks, gates, fences, construction boards, and dustbins. The product has not yet gained widespread production due to the disadvantages of high initial infrastructure investment, high technological expertise required, and waste sorting process. The advantages of the product are high durability, being waterproof, being bacteria-proof, low maintenance, and environmental benefits. Recycled plastic lumber have the potential which could serve as the decking material for the floors of the slum house as the short span of the houses do no usually go beyond 3 to 4 meters (approx. 10 feet). The spans of commercially available plastic lumber in the United States market are 8’, 12’, 18’, 24’, 40’ and 45’. (Hard Tool Process Fiberforce Recycled Plastic Lumber Size Chart, 2015). Recycled Plastic Lumber has great potential to have a positive impact on the environment as well as to help in housing construction. Due to the level of sophistication and infrastructure required for manufacturing, it is not feasible for the slum of Dharavi to manufacture the product in the existing small-scale cottage industry. Dharavi can only add to the value chain when it is involved in the segregation of products so that the laborers are
educated by the manufacturing companies about what type of commercial products can be recycled and how they can be sorted, cleaned, and prepared to be sent to manufacturing companies.

Figure 6-1. Recycled Plastic Lumber (Source: British Recycled Plastic)

6.2.2 PLASTIC WALL TILE

6.2.2.a INTRODUCTION

The plastic tile is developed out of a research project led by S.K. Dhawan, a scientist at the National Physical Laboratory (NPL) in India (Vyawahare, 2017). The tiles were demonstrated to be used as wall panels to create a bathroom sized room at an exhibition organized at Council of Scientific & Industrial Research (CSIR). The plastic items used in this product are mainly composed of a mixture of low-density plastic, high density plastic, polypropylene, and polystyrene. Plastic bags, bottles, milk packets, and sachets are used (Vyawahare, 2017). The materials are weather
resistant, thermally resistant, acid proof, durable and structurally stable at a lower cost than conventional materials. A company named Shayna EcoUnified India Pvt. Ltd adapted the technology developed by CSIR-NPL to develop plastic tiles. The plastics are collected by the company from various sources comprising rag pickers, households, NGOs, and other institutions. Most plastics are cleaned and sorted according to the polymer type and color. Then the plastic waste is shredded into small flakes and washed again. The flakes are dried using moderate heat and passed through specialized equipment that further segregate the products. The dry separated products are melted down and molded into a new shape under regulated temperatures. They are compressed into tiny pellets. The plastic pellets are then mixed with fillers and then molded into tiles. For fire safety the company has added fly ash with other flame retardants to the product and UV retardant for protection against sun (Shayna EcoUnified, 2017). Around 600 plastic bags are required to make one tile.

6.2.2.b APPLICABILITY IN DHARAVI

The product is meant to be used as wall tiles for the less privileged people in India. The exhibition demonstrated the use of the panels as an envelope of a public toilet. The advantages of the wall tile are that they cover less space than the brick envelope and thus provides them with more space in a context where every inch of space matter. A lighter upper floor means the thickness of the load bearing wall in the ground floor. Additionally they are better than the corrugated sheet metal envelope as plastic is not a good conductor of heat and the wall tile is much more durable.

6.2.2.c CONCLUSION

The wall tiles serve as a good alternative for the existing walls that are not load bearing in nature, and that is why they may be suitable for the upper floor constructions or for any public amenities such as toilets that are made of just one floor. However, they need a framework on which they can be attached or nailed. The production of the tiles requires technological
infrastructure and knowhow, and thus Dharavi can contribute to the informal collection of raw materials. The people in Dharavi are constantly repairing the houses due to poor quality materials and end up paying a significant sum over the years. The wall tile will be an improvement in terms of cost, quality, and comfort.

![Figure 6-2. Wall Made from Plastic tile on a Frame (Source: Malavika Vyawahare - Hindustan Times)](image)

### 6.2.3 PLASTIC ROOFING TILE

#### 6.2.3.a INTRODUCTION

Water sachets, plastic bottles, and sawdust are the main ingredients used in plastic roofing tile. The study of recycling was done in Ogbomoso in Nigeria where plastic material from trenches,
drainages, streets, dump sites, and eateries was collected (Temitope, Abayomi, Ruth, & Adeola, 2015).

The study was done in response to growing health concerns due to the detrimental effect of waste plastic, which causes blockage of drainage, suffocates animal life, prevents groundwater percolation, leaches of toxic elements, and causes other harmful effects. For the study, the plastics consisting of plastic bottles and water sachets were sorted and cleaned with detergent and water to wash out the impurities such as adhesives and dirt. The dried plastics were shredded. Powdery saw dust from mahogany and iroko tree were dried in the sun for one day. In the study, 320 grams of the shredded plastic was melted in an aluminum pot for 3 minutes and 100 grams of saw dust was added. The blended mixture was poured into a wooden mold and knocked to make any entrapped bubbles escape which could cause a crack in the tile. The tile is then cooled in air for 20 minutes in air. (Temitope, Abayomi, Ruth, & Adeola, 2015).

Various tests such as water absorption, crushing test, flammability test, and frictional test were conducted on the tile. There was no water absorption in the tile. The crushing strength of the plastic tile showed a 15% decrease in strength than a conventional tile, which means that it would not be good for loading applications. The composite flammability test by application of heat from oxy-acetylene gas also showed better results than conventional tiles, which split under flame, but no specific fire rating value was specified in the research (Temitope, Abayomi, Ruth, & Adeola, 2015).

6.2.3.b APPLICABILITY IN DHARAVI

The material qualities of the tile are suited to serve as a roofing tile as they are durable, light, and waterproof. Moreover, they would not corrode, unlike corrugated metal roofing, which shows signs of corrosion over time and leaks water. There is not much information on the insulation values of the plastic tile, but overall this kind of plastic roofing tile would be an improvement to the existing metal sheet used, as plastic is not a very good conductor of heat.
6.2.3.c CONCLUSION

The production of the plastic tile is very easy and achievable by the people of Dharavi as it does not involve any sophisticated technologies. Though the production of the plastic tile is low the safety of the tile needs to be considered as the plastic materials may start to leach toxic compounds when exposed to sunlight and heat. The long-term performance effects need to be checked before being produced. Another solution would be to use an additive that would inhibit the leaching of toxic compounds, as long as the additives do not have adverse effects. Thus, before being mass produced, research by Indian institutions is needed to check the long term adverse effects as well as to develop a possible solution to prevent the harmful effects.

Figure 6-3. Composite Tile Made from Recycled Plastic Materials in Nigeria (Source: Temitope AK)

6.2.4 UBUNTUBLOX

6.2.4.a INTRODUCTION

Ubuntublox is a compressed block made from unsorted waste materials. The material was developed in response to the Haiti earthquake by the fence builder Harvey Lacey (n.d.) who
invented a simple press to mechanically condense widely available plastic waste into building blocks called Ubuntublox. The apparatus is simple to use, can be locally built and carried by a single person. The prototypes made were successful from a structural point of view. Each prototype block made had a weight of about 3 kg. There was an economic question that arose concerning Ubuntublox, because if the recycling centers in developing countries could redeem these materials for their petroleum prices, then the material cost of the blocks is too valuable to be used as a block (Hebel, Wisniewska, & Heisel, 2014). These plastic waste materials could fetch higher prices being sold for their petroleum material rather than for their use as a building block. This realization led to the lookout for a material that had no material value. Styrofoam and agricultural wastes were the alternative materials used to make the blocks. The agricultural waste used for alternative materials consisted of remains of the Vetiver plant after processing of its oil. It is a waste product that is burnt with an accelerant, which releases pollutants into the atmosphere. Thus, the use of Vetiver plants in the block has positive environmental impacts. It is also an insect repellent, which makes it useful for the construction of homes but there are concerns for the durability of the product made from agricultural waste.

The advantages of the materials made with plastic waste over agricultural waste is that they never decompose which is a beneficial feature in construction. The block made from agricultural waste need an extra water protection layer of plaster to make the envelope resistant to water penetration. Materials made from either plastic or agricultural waste are lightweight, excellent insulators, and resistant to hurricanes and earthquakes. (Lacey, n.d.)

The standard size of the block is 200 mm x 400 mm and is load bearing in nature. It has been used for a single-story building. It requires stiffening with wire and rebar. Rebar is needed after four courses and the blocks are tied with wire. It requires a heavy base with earthbags, concrete blocks, or gravel bags. It can withstand a weight of 4,000 pounds. Fireproofing it requires a coating of stucco or plaster with steel chicken wire mesh, but it is not good for prolonged fire exposure.
6.2.4.b APPLICABILITY IN DHARAVI

Looking from the perspective of Dharavi, Ubuntublox seem to be a good solution for non-load bearing envelopes, but since it requires additional steel rods and chicken wire mesh for reinforcements and stiffeners, it adds extra financial burdens. The smooth finish of the wall made from the blocks could be achieved by an addition of plaster over a chicken wire mesh. Most of the Dharavi houses are already two or three stories high and are looking to add an extra floor with walls that are lightweight. Ubuntublox are lightweight in nature, but their use in the case study was limited to ground structures only. As evident from the background research, the single-story houses in Dharavi are often common public toilets or are used as recycling work sheds with high ceilings. The blocks could have use in the repairs or improvement of these single-story units.
6.2.4.c CONCLUSION

Since Dharavi is already an established slum, the scope of construction means only replacing old damaged portions of a wall or improving envelopes by the addition of new materials in place of the corrugated sheets. Due to the lightweight nature and good thermal resistant properties, the block could be applied as a wall envelope, but details must be resolved for the connection of the envelope to the floor and how to stiffen the envelope. To be used as an alternative for load bearing block in the ground floor, the structural capabilities Ubuntublox need to be tested for whether they can be used as walls in the upper floors. New business models with the support of the NGOs could examine Dharavi as the manufacturing center of the blocks, which could be transported to nearby villages where there is space to start up a new construction from the ground. Since this construction is good for resisting earthquakes, it could be transported to the nearby earthquake prone state of Gujarat, where the villages might find its use beneficial.

6.2.5 RECYCLED PLASTIC BRICKS

6.2.5.a INTRODUCTION

Recycled plastic bricks are developed by the architect Oscar Mendez in Bogota, Colombia. He formed a company called Conceptos Plásticos, which transforms plastic and rubber waste into construction materials such as bricks, beams, and pillars. The aim was to reduce the environmental impact of plastic by reusing it and to solve the housing crisis of the booming populations in Latin America. Collection of the materials is done by encouraging schools and community groups. They also train and educate communities about building their own houses (Winkless, 2016). The collected materials are segregated according to the type of plastic, and then cleaned and ground into fine powder. Small scale recycling is an established trade in Colombia. 40,000 small trucks and carts driven by people roam around the city and collect the
solid wastes that are deemed to be recyclable. The recyclers bring the scrap metals, plastic bottles, and other plastic items to a common shop where they are paid according to the weight of the materials. For bulk production the plastics are brought from these shops. The plastics used for the recycled plastic bricks are sourced from household plastic waste, battery packaging, and electrical waste such as old computers and television sets (Al Jazeera English, 2017). The different types of ground plastic is mixed according to a proportion that is a proprietary secret of the company. Additives are also added to the plastic that make the plastic more heat resistant. The mixed plastic is poured into a mold and heated exactly to the melting point of the mixture of plastic around 200 to 240 degrees centigrade so as not to burn the plastic and release toxic gases into the atmosphere. They are compressed into brick shapes. The design of the bricks is interlocking in nature such as LEGO blocks and do not need any adhesives. It makes a strong durable structure resistant to earthquakes and fire due to the adhesives put into the mixture. The company claims that it could serve as an alternative for wood construction, and thus the use of these plastic bricks could lead to less deforestation.

Figure 6-5 Child Carrying Plastic Brick (Source: Aljazeera)
6.2.5.b APPLICABILITY IN DHARAVI

Being lightweight and easy to build with, these recycled plastic bricks can serve as an effective replacement for the existing materials as a building skin. The fact that it can be quickly assembled and disassembled could be a good indicator of its applicability, which means that structures made of these bricks can be legally considered as impermanent structures. Research needs to be undertaken about the concoction of the different pellets of plastic that need to be mixed to make the bricks, as it is a proprietary secret of the company and also the source materials might be different. For mass production the collection of plastic needs to be efficient in handling a bulk number of products of the material that goes into making the bricks, as the plastic material content in each bottle or container is insignificant compared to the plastic content in the brick.

6.2.5.c CONCLUSION

In Colombia the houses were tested on open fields and were started from afresh. Plastic lumber was also developed by the company in order to act as peripheral floor and ceiling beams as well as posts. The plastic bricks interlock in these posts and beams, and there is no special jointing required. This will not be the case in Dharavi since the majority of the houses are already built and need some renovations where a damaged skin of brick wall or damaged sheet metal needs to be replaced. Thus, the plastic beams and posts do not have much opportunity of being used there, which means the bricks need to be load bearing in nature as in the existing scenario. Testing needs to be done on the effects of compression on the plastic bricks and whether they can replace the bricks of the lower floors. As for the uppermost floor, these plastic bricks can be used without considering their structural capabilities. The jointing of the brick wall with the floor and the ceiling need to be figured out in the Dharavi slums. The length of the plastic brick modules in Colombia is more than a foot long and may be close to two feet as estimated from the pictures and the video. The modules of 2 feet seems to be too long in the case of Dharavi, as the space
requirement of a wall face in Dharavi is much shorter and of a fixed length. A shorter length of a brick module would be more efficient to fill in the wall faces and reduce the wastage of the bricks, considering the extra length needs to be sawed or cut in some way. Shorter lengths make it possible to fill the gaps with some cement material rather than cutting portions of the brick. The edge conditions also need to be figured out in the case of the plastic bricks to suit the context of Dharavi, as the plastic brick walls are locked in on the plastic beams by a kind of tongue and groove joints.

Figure 6-6. Beam to Brick Connection of Conceptos Plasticos (Source: https://www.archinet.com)
6.3 BUILDING MATERIALS FROM CARDBOARD RECYCLING

6.3.1 CORRUGATED CARDBOARD POD

6.3.1.a INTRODUCTION

The corrugated cardboard pod is a housing project developed by Auburn University in 2001 using wax impregnated cardboard waste that cannot be recycled due to the wax content. The disadvantage of the material is that it became infested with wood worm. Bales of corrugated cardboard are used as a wall by stacking them up. They acted as a loadbearing wall over which a heavy timber beam and a roof was built. The bales were used in the foundation by being wrapped in plastic, and a concrete base is poured over the bales to support the wall (Michler, n.d.). The construction of the walls has a modular approach. The blocks are placed in a running bond pattern, and due to the high weight, the friction between the blocks does not require additional reinforcement. The gaps between the bales are filled with soil, Portland Cement, and cardboard shavings. Cross bracing cables were used in the prototype to stabilize the structure (Hebel, Wisniewska, & Heisel, 2014). The standard dimensions of the blocks used were 800 mm x 2000 mm with a height of 700 mm. The density of the material was 400 kg per cubic meter. It has high thermal mass and insulation properties. There is no evidence of how the block performs in rain and fire, but the fact that the prototype building still stands in good shape shows that rain might not affect the building as much if it is protected by a big roof. Also, a similar project named PHZ2 in Germany also used thick walls made from cardboard paper, and only the first 8-10 cm of the wall were affected by precipitation, which dried out in a short time.

6.3.1.b APPLICABILITY IN DHARAVI

The Corrugated Cardboard blocks have been tested to build walls from the ground. In Dharavi there is need for walls on the higher stories. Even if the cardboard blocks are used to replace the dilapidated wall of the ground floor, they do not seem to be a viable option as they
tend to occupy a lot more space due to their thickness. Making the blocks thinner would take away all the benefits gained from the blocks such as thermal mass and high insulation values, and they would be susceptible to rainwater penetration.

6.3.1.c CONCLUSION

The use of the blocks as a wall material does not seem to be a viable option as the 800-mm thick wall takes up too much space in the context of Dharavi where people fight for every inch of space. The other disadvantage of the material is that its density is high and it would be difficult to be used as walls in the higher floors. Corrugated cardboard waste could find its applicability in Dharavi if it is compacted to form wall panels or boards having the properties to resist thermal gain and rain water penetration.

Figure 6-7. Corrugated Cardboard Pod Project (Source: https://www.ruralstudio.org)
6.3.2 MODULAR ROOF

6.3.2.a INTRODUCTION

The modular roofing system named ModRoof made from cardboard and agricultural waste is founded by Hasit Ganatra, an engineering graduate from the University of Southern California who formed the company ReMaterials in India (REMATERIALS, n.d.). It took 300 attempts in two years to develop the product. In the slums it serves as an alternative roofing system to the expensive concrete slabs or the inexpensive corrugated metal sheets. The modular roof is made of two very easily available sources such as cardboard packaging materials and organic wastes such as coconut fiber. The cardboard is shredded and then blended to pulp with the addition of water. Organic fibers are added for reinforcement and the final mixture is poured into a mold. It is compressed cold to extract the water to form the hardened panel. The panels are heated and after drying a specially developed waterproofing paint is added. The modular panel can be interlocked with the surrounding panels, making it easy to install and maintain (Hebel, Wisniewska, & Heisel, 2014).

6.3.2.b APPLICABILITY IN DHARAVI

The modular roof has been implemented in the slums of Ahmedabad. The raw materials of cardboard and coconut waste as fiber can be easily sourced in the slum of Dharavi, and moreover they do not contain any toxic materials. This roof design provides better heat insulation, does not corrode, and provides protection from the rain. In the slum community in Ahmedabad the roof was available through a loan system. An average 23 square meter roof costs $1000, which is more expensive than a metal roof but cheaper than concrete construction. Customers used microfinance loans to buy the product paying around $50 a month (Rice, 2017). A similar micro-
financing scheme can be developed in Dharavi with the support of various non-profit organizations helping the people to fund the roofing materials.

6.3.2.c CONCLUSION

The modular roof is an ideal solution as a roofing options for the houses in the slums of Dharavi because it complements the existing construction methods and furthermore the production can be done without sophisticated technologies. The materials used for production are environmentally friendly and thus act as a viable replacement for the existing cement sheet roofing, which contains the carcinogenic material asbestos. This modular roof design eliminates the need of the people in slums to spend money on constant repairs of the roof annually. The modularity of this design makes it possible for a family to develop their roof incrementally depending on the financial capacity of the family. The roof created out of the modular roofs are sturdy enough so that people can walk and sleep on them – a common activity in the slums. It would benefit the people more if the cost of the material could be brought down as most people will think twice about a loan scheme for financing the roof. Most of the cost of the roof comes from applying the waterproofing paint which is expensive. The procurement of the raw materials would not be much of a difficulty in Dharavi, but the production of it would require technical knowledge of the proportion of mixtures used as well the type of waterproof coating.
Figure 6-8 Picture Showing Installed ModRoof Products (Source: http://re-materials.com/modroof)

Figure 6-9. Installation of ModRoof (Source: http://re-materials.com/modroof)
6.4 BUILDING MATERIALS FROM GLASS RECYCLING

6.4.1 RECYCLED GLASS TILES

6.4.1.a INTRODUCTION

The recycled glass tiles were produced out of a waste processing system named Waste Labs which created a scheme for local collection, processing and transformation of waste in London. The recycled glass tile initiative was called Glass Lab. The Glass Lab is developed by a Royal College of Art student named Diana Simpson Hernandez. She was examining local resources and waste materials to produce alternative economies to empower businesses and communities. Glass is collected from local businesses and is used as the raw material. The collected glass bottles are crushed on site, cleaned, and sorted into fine, medium, and coarse filaments, which are combined with a vegetable bio-resin binder to produce strong weatherproof materials such as tiles, bollards, and street furniture (Chang, 2013). The recycling process does not require a massive quantity of energy compared to the conventional recycling process which involves melting of the product at high temperatures.

6.4.1.b APPLICABILITY IN DHARAVI

People in Dharavi decorate the interior floor of the houses with tiles. With local production and decreased cost, the tiles have a potential to be sold both in the formal and the informal market.

6.4.1.c CONCLUSION

The glass tile is easy to produce, and the production of it does not involve sophisticated technologies nor does it involve any harm to the people as the materials are non-toxic in nature.
The small industrial work sheds are suitable for the production with the involvement of manual labor in Dharavi.

![Glass Tiles from Waste Lab (Source: www.archilovers.com)](image)

**Figure 6-10. Glass Tiles from Waste Lab (Source: www.archilovers.com)**

6.4.2  **RECYCLED GLASS WALLS OR PANELS**

6.4.2.a  **INTRODUCTION**

Recycled glass wall is a product that uses recycled glass from bottles for cladding purposes. It involves a low-tech approach of recycling the glass waste of bottles meant for landfills, where the bottles are smashed into smaller pieces to be used as a finishing material. The color of the glass cladding depends upon the colors of the bottles used. Patterns and artwork can also be created on the panels as the crushed glass is hand applied onto the substrate. They find its
application in luxurious and commercial settings (Alternative SURFACES, n.d.). The hard and non-porous characteristics prevent mold and bacterial growth. They can serve as a cheap and durable alternative to the quartz plastering. The glass can be broken down into similar dimensions of quartz and fixed onto one inch of white cement (Bahamon & Sanjinés, 2010). A fine example of this was implemented in a kind of housing named Casas Chorizo in Buenos Aires in Argentina. The refurbishment of one of these houses led a family to use these recycled glass walls in to reflect indirect light into the patio. A tighter budget led them to the use of these glass walls, which proved to be aesthetically pleasing and required no maintenance.

6.4.2.b APPLICABLITY IN DHARAVI

Dharavi receives a lot of glass products in the form of glass bottles and medical vials which are of different sizes and colors. Manufacturing of the glass panels involves very low-tech technology and can be easily implemented by the people of Dharavi. The retail shops in and around Dharavi could serve as a potential market for the building product as a low cost and durable decorative wall panel for the interiors.

6.4.2.c CONCLUSION

The manufacturing side of the glass walls is easily attainable and depends mostly on manual labor. An organized business strategy is necessary to scale it up and reach the customers of the formal market in order for recycled glass panels to be a successful venture as the number of retail shops in Dharavi requiring decorated wall panels will be too small for a viable market. Large commercial shops and retailers outside Dharavi having large surface areas to cover up could find this wall panel an attractive solution with low prices compared to conventional cladding materials.
Figure 6-11. Use of Recycled Glass in Walls in Chalu House (Source: www.dezeen.com)
6.4.3 WASTE GLASS AS AGGREGATE IN CLAY BRICK

6.4.3.a INTRODUCTION

Waste glass when added into brick clay led to an improvement in some of the properties of the clay brick. The testing was done at the Afyon Kocatepe University in Turkey where waste glass is mixed with the clay (Demir, 2009). The brick clay was crushed by a roll crusher and sieved through a 1 mm sieve while the waste glass was crushed with a jaw crusher and sieved through a 0.5 mm sieve. Four different mix samples of different proportions of waste glass were fired at three temperatures of 850°C, 950°C, and 1050°C in an electrical kiln. This led to the 12 kinds of samples and properties that were studied, such as apparent porosity, bulk density, loss on ignition, water absorption, and compressive strength. The mix proportions used were 0%, 2.5%, 5%, and 10% by weight of waste glass to clay and the size of the test specimen was 75 mm x 40 mm x 100 mm.

The drying and the firing shrinkage decreased with increasing amounts of waste glass, and thus it caused a positive effect by reducing any internal strain during the drying process. There was no change in bulk density with regards to the amount of waste added or the temperature of the kiln, but the apparent density of the samples fired at higher temperatures of 1050°C was lower. The water absorption values decreased with increasing firing temperature and decreased with increasing amounts of waste glass. The compressive strength of the 10% mix were 12-14% higher than the 0% mix. The 10% mix fired at 1050°C demonstrated a compressive strength of 29.35 MPa (Demir, 2009).

6.4.3.b APPLICABILITY IN DHARAVI

The requirement of bricks in the informal settlement would be limited to repairing any damaged brick walls in the ground floor or to improve the lightweight metal envelope of the upper floors.
6.4.3.c CONCLUSION

Though the bricks with recycled glass additives are an improvement to the conventional bricks, the local production of the bricks with glass waste will be very polluting and thus should not be encouraged. The kiln used for clay burning for the pottery industry is itself very polluting and thus any additional industry encouraging the open burning of kilns will cause smoke pollution affecting the residents as well as the city. Thus, in Dharavi the contribution to the value chain of the industry needs to be limited to sorting the material so it can be sent to specialized cement or clay making factories.

6.5 BUILDING MATERIALS FROM PAPER RECYCLING

6.5.1 NEWSPAPER WOOD

6.5.1.a INTRODUCTION

Designer Mieke Meijer and the company Vij5 from Netherlands developed a simple method of converting waste paper into a composite material having wood-like properties. The paper waste is soaked in glue and wrapped along a linear axis on a wooden log. The method mimics the circular rings of a tree log when it is cut. The material can be treated like any wood and it could be drilled, cut, milled and nailed (Hebel, Wisniewska, & Heisel, 2014). Waterproofing can be done by applying a finish coat of varnish or wax. Any application done by wooden boards could be achieved by this new material. At this point it does not aim to be a large-scale alternative to wood, but this is developed to tackle the surplus of waste newspaper to turn it into something useful. At the end of the lifecycle as a building material, the designer wanted it to be reintroduced into the same cycle, but attention must be given to the chemical nature of the glue and the waterproofing coating. The glue utilized needs to be free of solvents and plasticizers to be
recycled again. There is a limitation to the size of the wood also. The maximum size of the log that can be achieved is the size of an open newspaper which is around 380 mm.

6.5.1.b APPLICABILITY IN DHARAVI

Newspaper wood could have some uses in Dharavi. Since it has wood-like properties, it could find its applicability in making furniture in the slums, lintels for windows, and ladders and boards for the lofts. It could also be used as a decking material for the floor in place of the natural grey stone tile, provided that a reinforcement material is inserted into the material to achieve the desired flexural strength. For structural uses, research and testing needs to be facilitated to understand limits of the strength of the material and the potential applicability. The boards could also be used to create wall panels with an infill material sandwiched between the two layers or be used as a laminate.

6.5.1.c CONCLUSION

Newspaper wood is a new technology and the technology to make it is very simple and low cost. Thus, the production of the material seems a viable option in Dharavi. The newspaper wood has been explored to be used in furniture, but its use as a sandwiched wall panel has not been explored much. Even if it is used as a decking material for a roof or a slab, further research is needed into how the span of the material relates to the maximum load capacity of the deck and the long-term effects of the use of the product.
6.5.2 PAPERTILE

6.5.2.a INTRODUCTION

Paper tile vault is a product developed by the BLOCK Research Group for use in their research of vaulting techniques (Hebel,Wisniewska, & Heisel, 2014). Paper and cardboard are used as the input construction material. Cardboard and paper are shredded and re-pulpled by adding water to it. The material dissolves to form a mass which can be pressed to a desired shape. The combined material is known as papier mache and is compressed into brick tiles with the addition of an organic wheat starch paste before the process of pressing. The wheat starch paste increases the compressive strength. Thinner blocks take less time to dry. The final texture of the brick depends upon the pulp of the paper used. The tiles can also be glued together with mortar. Fireproofing can be done with the addition of layers of ingredients such as borates and waterproofing by varnishing. (Hebel, Wisniewska, & Heisel, 2014)
6.5.2.b APPLICABILITY IN DHARAVI

Paper tile could find its application as a decorative floor tile in the houses of Dharavi. It is a common custom in India to use glossy ceramic tiles in the floors of the houses. Following the trends of the middle and the upper class, the people in the slum aspire for a better aesthetic for the interior of their homes by using floor tiles. The paper tile could make its way into both the formal and the informal market if it can give the clean smooth finish of the existing ceramic tiles by a coating of any kind of shellac or varnish material. Attention needs to be given to the material of the organic paste used, as well as the fireproofing and the waterproofing ingredients so that they can be easily recycled at the end of the life cycle. The paper tile could also serve as a roofing tile that can span between the wooden joists of the building roof and overlap at the edges. However, attention is needed to be given to the long-term effects of rain and sun on the waterproofing coating used.

6.5.2.c CONCLUSION

The paper tile can serve the market of Dharavi as the input materials are easily available to the people of Dharavi. The production of the paper tile involves a low-tech approach that can be easily implemented in the small working sheds of Dharavi.
Figure 6-14. Paper Tile Bricks Arranged Next to Each Other and Glued Together by a Fast Setting Mortar (Source: - Building from Waste: Recovered Materials in Architecture and Construction)
6.6 BUILDING MATERIALS FROM LEATHER RECYCLING

6.6.1 STRUCTURAL SKIN

6.6.1.a INTRODUCTION

Waste leather is used as the material to create a slat-like product that is currently being used to make furniture products. It is a new material that has wood-like properties and the surface texture looks like marble paper (Smow, 2015). The product was developed around 2015 by the Spanish designer Jorge Penadés, a graduate from Madrid’s Istituto Europeo di Design (IED). The product is well recognized and has a spot in the permanent collection at the Vitra Design Museum, and it also won the AD Nuevos Talentos Award from Spanish Architectural Digest magazine (Jones, 2017). The leather industry is inefficient as the manufacturing process leads to a significant amount of leather waste. The quality of the leather depends upon what part of the animal the materials came from, and the higher the movement the lower the quality. Only 43% of each hide is of a high quality (Materia, 2015). Much of the leather goes to waste, and leather industries produce a large number of leftovers and offcuts. The waste leather is shredded and then combined with bone glue as binder to form a lumber-like product. Bone glue comes from the byproduct of meat processing where bone is ground to powder and dissolved in water. After boiling they can be dried to form the bone glue. The strips are added to the glue and then placed into iron molds to be compressed. The top layer is shaved to get a smooth appearance (Morby, 2015). Then a coating of shellac is applied to the product. Initially the production of leather tiles was attempted, but it was hard to keep them flat (Penadés, n.d.).

6.6.1.b APPLICABILITY IN DHARAVI

The material could have potential to be used as a replacement for the wooden slats that are widely used in Dharavi as frames for the metal skins of the buildings. The slats may be used to make various furniture as is done by the original recycled product.
6.6.1.c CONCLUSION

The product can be built without sophisticated technology by the people in the slum. There is an established leather industry whose waste would be useful for the production along with the bone glue that can also be sourced from animal bones out of the local meat shops in and around Dharavi. However, the development of the product needs more research as properties such as the durability and strength of the product is unknown.

Figure 6-15. Structural Skin - New Material by Jorge Penades at DMY Berlin 2015 (Source: www.smow.com)
6.7 BUILDING MATERIALS FROM TETRA PAK

6.7.1 TUFF ROOF

6.7.1.a INTRODUCTION

TUFF roof is a kind of a corrugated roofing sheet developed from Tetra Pak cartons by Daman Ganga Paper Mill in India (Hebel, Wisniewska, & Heisel, 2014). Tetra Pak consists of layers of cardboard, plastic films and aluminum foil. It is difficult and expensive to segregate the products for the recycling process, and furthermore the machine needed to recycle Tetra Pak is not usually found in the developing world. However, the combination of the products is being used as an advantage which resulted in the realization of using it in the construction sector. The advantage of the corrugated roof made out of shredded Tetra Pak over corrugated iron or cement sheets is that it is non-corrosive, light, fire-proof, heat-reflective, and lower in production costs. The production method consists of placing the shredded cartons in a mold and then applying heat to activate the inherent plastics, paraffin, and glues to act as the new adhesive. Finally, the heated material is compressed to achieve the corrugated shape (Hebel, Wisniewska, & Heisel, 2014).

6.7.1.b APPLICABILITY IN DHARAVI

The TUFF sheet would be extremely useful in Dharavi, as it is lightweight and provides suitable resistance to heat conduction compared to metal sheets. Moreover, it is a good alternative to the existing asbestos corrugated sheets due to health concerns as asbestos exposure has been found to correlate with carcinogenic diseases. Boards made out of TUFF sheet material could also serve as wall panels, which would further improve the comfort conditions of
the interior during the summer months. The material does not need fastener for jointing and can be achieved by nailing. Though there is far less evidence of recycling Tetra Pak in Dharavi, its potential as a part of the waste material inventory cannot be ignored, as environmental groups through initiatives such as “Go Green with Tetra Pak Recycling” have demonstrated the recycling potential of it by collecting over 6 lakh cartons from Mumbai houses since its inception in 2010 (Tetra Pak Association, 2015).

Figure 6-16. Tuff Roof Production and Use in Houses (Source: - Building From Waste: Recovered Materials in Architecture and Construction)

6.7.1.c CONCLUSION

The Tetra Pak TUFF roof material is very suitable to fulfill the needs of the people and utilizes a common household discarded waste product. The production of the material by the people of Dharavi needs to be figured out as the production of it requires compression machines like the ones used in the corrugated metal sheet production industry. The people of Dharavi have a lot of shredding machines for the plastic industry that could be used for the Tetra Pak shredding but they lack compression machines. Financial support from the social organizations might be needed to invest in a compression machine for local production.
6.8  BUILDING MATERIALS FROM E-WASTE RECYCLING

6.8.1  ADMIXTURE IN CEMENT MORTAR FROM PRINTED CIRCUIT BOARDS

6.8.1.a  INTRODUCTION

The non-metallic waste of the printed circuit board can act as admixture to cement mortar resulting in an increase in air-content of cement and improves the water content of fresh mortar and decreases the bulk density of cement. Printed circuit boards contain metals such as copper, aluminum, iron, gold, tin, antimony, lead, and tin, as well as non-metals consisting of thermosetting resins and glass fibers (Theo, 1998). The amount of valuable metals available in the PCB is what drives the recycling and the recovery of metals. The separation of metals is done by smelting, pyrolysis, shredding, separation, and chemical treatment, which are extremely energy intensive, and extreme precautions are needed due to the high potential of exposure to the toxic byproducts of dust and gas arising from the processes. These processes of recycling cannot be done in an informal recycling center responsibly and safely. Non-metals constitute about 70% of the materials in printed circuit boards (Veit, et al., 2005). The non-metals are conventionally incinerated or sent to the landfills causing adverse impacts on the environment.

The non-metallic powder from the printed circuit board is added as admixture to the cement mortar in various proportions. It leads to a lower bulk density of cement and a higher air content, which is good for construction. The ratio of the mass of the waste non-metallic portion to the cement mortar between 5 to 10% yield good compressive, and flexural strength. For a 10% mix cured for 28 days, there is an 18% reduction in compressive strength, 11% reduction in flexural strength and a negligible change in shrinkage rate. The strength decreases much more rapidly if the proportion of the mixture of non-metallic part is increased more than 15%. A mix below 15% shows better water capillary control than a 0% mix and the admixture improve the water retention property of cement mortar (Wang, Zhang, & Wang, 2012).
6.8.1.b  APPLICABILITY IN DHARAVI

Electronic waste poses little risk to the people or the environment until it is dismantled to recover the precious metals. The current trend of informal recycling of electronic waste is harmful and should not be encouraged until proper protocols are put in place. Dharavi can only contribute to two types of labor for a circular economy of electronic waste. One is to sort the products to the appropriate recycling centers, and the other is to extract the products safely for further processing or extraction in a formal recycling center armed with proper gear and knowledge, supervised by chemical or metallurgical engineers. Initiatives such as the government authorized electronic waste recycler named E-Parisaraa Pvt. Ltd in Bangalore could be implemented. The objective of E-Parisaraa is to create an opportunity to extract the raw materials such as metals, plastic, and glass from electronic waste using simple, cost-efficient environmentally friendly technologies suitable to Indian conditions (E-Parisaraa Private Limited, 2005). It has major companies such as IBM, Tata Elxsi, ABB, HP, Infosys, Intel, Sony, Siemens, SBI, Motorola and Philips as its clients. Most of the software firms have agreements with the company to collect their e-waste and E-Parisaraa pays these firms for their e-waste.

6.8.1.c  CONCLUSION

Recycling of electronic waste is one of the most difficult processes compared to recycling of other products due to the diversity and volume of composite products of metals and non-metals, which are hard to extract using low cost technology. Recycling of electronic waste is harmful to the people and needs to be regulated. A top down strategy is essential for dealing with recycling of electronic waste. With the growing middle-class population consuming more and more electronic items and discarding items at an exceeding rate, electronic waste will be a major concern in the coming years and effective ways of managing electronic waste need to be tackled. Policies or incentives should discourage the informal dismantling of electronic products that carry potential risks to the recycling worker’s health and release of toxic pollutants in the atmosphere and to the general population.
The strategy of EPR (Extended Producer Responsibility) may help recycling and remanufacturing initiatives (Lindhqvist & Lidgren, 1990). EPR is a concept formally introduced in Sweden by Thomas Lindhqvist in a 1990 report to the Swedish Ministry of the Environment whose objective was to make the manufacturer of the product responsible for the entire life-cycle of the product especially for the take-back, recycling, and final disposal. This means they are financially responsible for the costs of collecting, which could potentially discourage the informal dismantling of the product if a good buyback price could be availed from the manual labor of collecting, sorting, and diverting it to appropriate recycling centers.
7. APPLICABILITY OF THE CASE STUDY BUILDING MATERIALS IN DHARAVI

7.1 RATIONALE OF THE ANALYSIS

This chapter analyzes the case study building materials in two different ways. They are presented in Chapters 7.2 and 7.3, respectively. The first analysis identifies the essential factors that are pertinent to development of a circular economy with these case study building materials in Dharavi. The existing literature on social, cultural, housing and entrepreneurship activities of Dharavi brings out the factors that need attention for implementation of this circular economy. It is an analysis of the suitability of the case study building products to contribute to a circular economy in the context of Dharavi. It gives us a measure of difficulty to implement a case study building product in the context of Dharavi. This takes into consideration the appropriateness of material properties of the product to the existing housing, the production difficulties, possible demand of these products outside of Dharavi and whether the product needs any further development or research to make it more suitable to the local context. These factors help to identify any entrepreneur or social organizations about the issues or steps to take into consideration if a circular building industry is to be made in Dharavi, involving the people of Dharavi in the processes of collection, manufacturing and production. This analysis will also help to assess the extent of involvement of the people of Dharavi to be involved in the processes of collection, manufacturing and production keeping in mind the safety and health issues of the people.

The second analysis in Chapter 7.3 is an elaboration of the factor ‘Suitability of Use’ mentioned as one of the factors in Chapter 7.2. The previous chapter focuses on the factors of implementing a circular economy. Out of the five factors, the factor ‘Suitability of Use’ is an indication whether the primary use of the case study product is an improvement compared to the conventional building material used in Dharavi. This does not elaborate on the potential uses
of the building product in various parts of a building, its scope of improvement, advantages and disadvantages. This is done in the next analysis of Chapter 7.3 which divides the house into seven constituents and elaborates on the usage of the product in different constituents of the house. The seven constituents are the load bearing envelope, the non-load bearing envelope, the flooring elements, the roofing elements, the finish material and the openings. The products are analyzed according to its applicability in each of the seven constituents of the houses. The advantages and drawbacks of the building product in the use of the building product in these constituents are discussed. These advantages and disadvantages discussed in Chapter 7.3 are limited to the use of the product and does not consider the issues of manufacturing as they were discussed in the previous analysis of Chapter 7.2. This helps to understand the potential areas where research could be further conducted:

- by material scientists to improve the material qualities of the product or to test the strength characteristics of the product
- to identify the presence of any harmful elements in the material
- by architects and product designers to design the details of the product to make it adaptable to the needs of the context
7.2 ANALYSIS OF THE CASE STUDY BUILDING MATERIALS IN THE CONTEXT OF DHARAVI

The study of the existing nature of the housing, living conditions as well as the case studies of the building materials from waste lead to understand the potential factors which are important to the establishment of a circular economy of building materials from waste. The primary five factors that have been identified are:

1) Suitability of Use in Dharavi
2) Suitability of Use in Formal Housing/Buildings
3) Manufacturing Inventory Needed for Production
4) Suitability of Local Production
5) Availability of Technological Knowledge/Research

The factors are explained below.

1. Suitability of Use in Dharavi

The criterion is based upon the housing needs of the informal people. The needs of the informal housing are based from the existing literature of Dharavi.

The housing needs are:

- Durable products which do not need periodic maintenance
- Strong lightweight load bearing materials enabling them to build higher
- High thermal resistivity of the envelope
- Resistant to rainwater penetration
- Materials to be modular in nature so that they can be manually built
- Thin building envelope is preferred as thin envelope provides more usable space
2. Suitability of Use in Formal Housing/Buildings

The criterion is based upon whether the building product will be useful as an alternative product in the formal building market. The requirements of the formal building products are: -

- Durable products which do not need periodic maintenance
- High thermal resistivity of the envelope
- Resistant to rainwater penetration
- Can be implemented into the existing formal method of construction
- Can be manufactured in bulk amount

3. Manufacturing Inventory needed for Production

The criterion identifies whether supplementary or new machineries are needed for production of the building material from the waste inventory.

4. Suitability of Local Production

This criterion indicates whether the manufacturing inventories can be installed in the work sheds of Dharavi as well as whether they can be operated by the people with minimal technical knowledge.

5. Availability of Technical Knowledge/Research

This criterion is based upon several sub-criteria which are as follows: -

- Adaptation of the Case study material to the Local Context - (Pre-Production)
  Since the commercial products vary from one region of the country to another research is needed to adapt the building product from the case study into the local context. This would involve identifying the specific commercial products and their material composition which can be used to build the product. This knowledge would be beneficial to inform the people involved in the sorting process in Dharavi
how to manually prepare the product for further production which require sophisticated technological machineries.

- **Material Characteristics Information** - Whether there is sufficient research available for the product to be used in housing. Properties like compressive strength, flexural strength, insulation value, water permeability and fire resistivity should be tested to judge the suitability of the product.

- **Scope of Improvement** - If any of the characteristics mentioned above need to be improved for better performance of the product. Research needs to be undertaken if it’s possible the required material characteristics of the product.

- **Check whether the product is environmentally responsible** - Any concerns with safety involved in the production process as well as concerns with any toxic effects in the lifecycle of the product (for example leaching of any toxic material of a plastic product due to exposure to high temperature or ultra-violet radiation).
<table>
<thead>
<tr>
<th>Building Materials from Waste</th>
<th>1. Suitability of Use in Dharavi</th>
<th>2. Suitability of Use in Formal Housing/Buildings</th>
<th>3. Manufacturing Possible with Existing Inventory</th>
<th>4. Suitability of Local Production in Dharavi with existing or new manufacturing inventory</th>
<th>5. Availability of Technological Knowledge/Research</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td>Plastic</td>
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</tr>
</tbody>
</table>
| 01 Structural Plastic Lumber| ✓                               | ✓                               | ❌                                | ❌                                               | ❌                               | 3. Manufacturing requires installation of new machineries and not possible within any existing machineries used in other local businesses. Products can only be prepared until the processes of sorting, shredding and washing in Dharavi.  
4. Existing production methods require specialized heavy machineries in assembly line production demanding large space for installation.  
5. Technical Knowledge and research is required in terms of identifying the specific commercial plastic products in the local context which can be sorted and processed further for production. Involvement of material scientists and structural engineers are needed to develop the material from a molecular level from existing plastic products and testing is needed to understand the compressive strength, flexural strength and the fire resistivity of the product. |
| 02 Plastic Wall Tile        | ✓                               | ✓                               | ❌                                | ❌                                               | ✓                               | 3. Specialized machineries of melting, molding, and compression are used in the case study which are not available in Dharavi. Products can only be sorted, shredded and washed in Dharavi.  
4. Existing production requires specialized machineries in assembly line production demanding large space for installation. |
| 03 Plastic Roofing Tile     | ✓                               | ❌                               | ✓                                | ✓                                               | ❌                               | 2. Not suitable in existing urban construction but could find its applicability in the rural informal market as roofing tiles.  
5. The case study is intended to deal with low quality plastic products. Research is required to identify which commercial plastic products are suitable. |
suitable in the Indian context that can be locally produced in Dharavi. Testing is also required for long term effects of sun on the material, durability, check for any potential toxic leaching substances and fire resistivity of the material.

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<th>04</th>
<th>Ubuntublox</th>
<th>X</th>
<th>X</th>
<th>✓</th>
<th>✓</th>
<th>✓</th>
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<tbody>
<tr>
<td>1.</td>
<td>Takes up too much floor space and needs steel stiffener rods that are expensive.</td>
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<td>2.</td>
<td>Not suitable in the existing urban framework of urban construction but could find its potential application in rural informal settlements where availability of open space is not an issue and the buildings need to be earthquake resistant.</td>
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<tr>
<th>05</th>
<th>Recycled Plastic Bricks</th>
<th>✓</th>
<th>✓</th>
<th>X</th>
<th>X</th>
<th>X</th>
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<tbody>
<tr>
<td>3.</td>
<td>New machineries of compression, melting, molding and a cooling tub is needed to cool off the plastic in the mold. The material can only be prepared in Dharavi until the manual processes of sorting, shredding and washing.</td>
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<td>4.</td>
<td>The machineries along with the cooling tub used in the case study for production demand large space and thus not suitable for production in the informal settlement where there is an acute shortage of space.</td>
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<td>5.</td>
<td>Technical Knowledge and research is required in terms of identifying the specific commercial plastic products in the local context which can be sorted and processed further for production and the proportion of different plastics to be mixed and fed into the molding process. Other essential studies need to determine the long-term effects of heat and ultra-violet radiation on the plastic, potential toxic leaches and the fire resistivity property of the material.</td>
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<thead>
<tr>
<th>06</th>
<th>Corrugated Cardboard Pod (Wax Impregnated cardboards)</th>
<th>X</th>
<th>X</th>
<th>✓</th>
<th>✓</th>
<th>X</th>
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<tbody>
<tr>
<td>1.</td>
<td>Not suitable in terms of durability, fire-resistivity, prone to be infected by insects and takes up too much space.</td>
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<td>2.</td>
<td>It is not suitable to be used as a building product in the formal market as well. It may find it’s applicability as a load bearing wall for any public space in a rural urban area but would require long overhangs on top of it to protect it from rainwater damage</td>
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<td>5.</td>
<td>Although the building product has excellent structural and insulation properties research is needed to improve the durability of the product.</td>
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<tr>
<td>No.</td>
<td>Building Product</td>
<td>Suitable</td>
<td>Neutral</td>
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<tr>
<td>07</td>
<td>Modular Roof</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>3. Machineries for extrusion are needed.</td>
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<tr>
<td></td>
<td><strong>Glass</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>08</td>
<td>Glass Tiles</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>5. The building product is very easy to produce with manual labor, but testing is needed to understand the compressive and flexural strength.</td>
</tr>
<tr>
<td>09</td>
<td>Glass Walls/panels</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Note: The building product is a plaster made from crushed glass applied on walls or panels.</td>
</tr>
<tr>
<td>10</td>
<td>Glass as Aggregate in Clay Brick</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>4. Although it is possible to make clay products in the informal settlement with the help of the heating kilns used for pottery but it is not suitable for mass production of due to space availability issues as well as pollution caused by burning of the kilns. Regulated production methods would be preferred, encouraged and supported for environmental and safety concerns.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Paper</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Newspaper Wood</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>1. Although suitable but the long-term durability is unknown and need to be investigated</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5. Research is needed to investigate the properties of strength of the material as well on the water resistivity of the product</td>
</tr>
<tr>
<td>12</td>
<td>Papertile</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>1. Although suitable as a product but long-term durability is unknown and need to be investigated</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5. Research is needed to investigate the properties of strength of the material as well on the water resistivity of the product</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Leather</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Structural Skin</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>1. Although suitable as a product but long-term durability is unknown and need to be investigated</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5. Research is needed to understand the properties of structural strength of the material as well as its durability in terms of its response to heat, sunlight and water to understand its limits of application as a framing material.</td>
</tr>
<tr>
<td>Tetra-Pak</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Tuff Roof</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>2. The tuff roof is not compatible with the formal construction techniques but is extremely suitable for the housing conditions of the rural informal settlements</td>
</tr>
</tbody>
</table>

| E-Waste | | | | | |
|---|---|---|---|---|
| 15 | Non-Metallic PCB as Cement Aggregate | ✓ | ✓ | X | X | 3. Manufacturing is not possible with existing infrastructure |

4. The building product is made from the by-product after Printed Circuit Boards have been recycled to extract valuable metals with advanced machineries in an industrial setting. Thus, it is not possible to manufacture the product. Dharavi can only contribute to the manual labor work needed to dismantle the product, but this manual work needs to be well supervised, educated or be equipped with protective gears for the safety of the workers from the toxic elements present in the electronic waste.

5. Research is needed to understand if the Brominated Flame Retardants (less than 2%) present in the non-metallic powder have any adverse long-term effects on human health or whether they can be extracted from the powder before using it as an admixture.
7.3 POTENTIAL USES OF THE MATERIALS IN THE INFORMAL HOUSING OF DHARAVI

The slum houses are systematically divided into parts where the potential uses of the building material could serve its purpose. The house is divided into the following seven parts - the load bearing envelope, non-load bearing envelope, the flooring system, the roofing system, furniture and the openings of door and windows. The potential applicability of the building products in different parts of the informal house is summarized.

7.3.1 LOAD-BEARING ENVELOPE

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
</table>
| 01) Recycled Plastic Bricks  | • Can be used as an alternative to load bearing wall in place of conventional brick having great durability, water resistivity and heat resistivity.  
• Lighter than conventional brick. | • Long term effects of high temperature and ultra-violet radiation can cause toxic leaching and need to be studied.  
• Flame resistivity of the product is unknown and needs to be investigated | • The case study use demonstrated the use of the building product as a load bearing wall only in one storey building. Its strength performance in higher storied buildings is unknown. |

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
</table>
| 02) Corrugated Cardboard Pod | • Load bearing in nature and provides great thermal mass that keeps interior cool | • The width of a unit is around 800 mm which takes up lot of the space and thus it is not suitable in informal settlements where every inch of space is valuable.  
• Requires steel stiffener rods which increases the cost.  
• The case study use demonstrated the use of the | • Made from wax impregnated cardboard paper |
building product as a load bearing wall only in one storey building.
- Rain affects the first 100 mm thickness thus questioning the durability of the product.
- The product is not fire resistant and prone to get infested by insects.

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
</table>
| Structural frame in the Vertical Building Envelope | • Can be used as structural framework as columns and beams in place of the expensive steel I-section beams spanning short lengths  
• Lightweight in nature and durable  
• Resistant to corrosion | • Jointing or connection points of the products with the lateral beams need to be figured out as the structural plastic lumber cannot be welded together like the case of steel beams. |                                           |
### 7.3.2 NON-LOAD-BEARING ENVELOPE

#### 01) Structural Plastic Lumber

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
</table>
| Non-Structural stud frame in the vertical envelope | • Strong lightweight in nature having wood like properties  
• Resistant to corrosion | | |

#### 02) Tetra-Pak Boards

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
</table>
| Sheathing board | • Can serve as a thin strong lightweight building envelope  
• Heat, flame and water resistant  
• Resistant to corrosion  
• Can be nailed to overlap with other boards | • The envelope not being load bearing, interior lofts along the envelope will be difficult to make. | • A bracing system is needed along with the wall envelope |
03) Leather Slats

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Structural frame in</td>
<td>• Very easy to manufacture locally</td>
<td>• The strength of the material is unknown and thus its use as long structural frames need to be</td>
<td>• Made from leather and bone glue. The frames are mainly used as furniture parts and thus it’s long term effects need to be</td>
</tr>
<tr>
<td>the building vertical</td>
<td>• Can serve as an alternative building material to wooden slats used as</td>
<td>investigated.</td>
<td>investigated before being used as building parts</td>
</tr>
<tr>
<td>envelope</td>
<td>a girt framing member (short span horizontal beams) or as a noggin piece</td>
<td>• Long term durability of the product is unknown as the binding material is made from bone glue</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>which might get affected if rain water penetrates the waterproof coating.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Fire Resistivity of the product is unknown</td>
<td></td>
</tr>
</tbody>
</table>

04) Newspaper Wood

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Structural short</td>
<td>• Can serve as an alternative building material to wooden slats used for</td>
<td>• Fire Resistivity is unknown</td>
<td></td>
</tr>
<tr>
<td>horizontal frames/girt</td>
<td>a girt framing members (short span horizontal beams) or as a noggin piece</td>
<td>• The strength of the material is unknown and thus its use as long structural frames need to be</td>
<td></td>
</tr>
<tr>
<td>in the building</td>
<td></td>
<td>investigated.</td>
<td></td>
</tr>
<tr>
<td>vertical envelope</td>
<td></td>
<td>• Long term durability of the product need to be investigated</td>
<td></td>
</tr>
</tbody>
</table>
### 05) Plastic Wall Tile

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheathing Wall Panel</td>
<td>• Lightweight and durable</td>
<td></td>
<td>• A bracing or framing system is required</td>
</tr>
<tr>
<td></td>
<td>• Resistant to water and heat</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The product is protected by flame retardants and ultra-violet protection agents</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 06) Glass Wall Panels

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>A decorative finish material on the wall envelope</td>
<td>• Prevents mold and bacterial growth</td>
<td>• Water proofing properties are unknown.</td>
<td>• It is a cement paste added with crushed glass which requires a base wall or panel to be applied to.</td>
</tr>
<tr>
<td></td>
<td>• Requires no maintenance</td>
<td></td>
<td>• If the product exhibits good water proofing properties, they can be used on top of panels made from waste like cardboard and paper which require a water proof coating.</td>
</tr>
</tbody>
</table>

### 7.3.3 FLOORING ELEMENTS

### 01) Structural Plastic Lumber

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooring Joist</td>
<td>• Can be used as an affordable alternative to structural I-steel beams</td>
<td>• Strength characteristics need to be investigated</td>
<td>• Structural analysis is needed to figure out the sectional dimension of the lumber required to span the floor of the house which is related to the material strength characteristics of the product</td>
</tr>
<tr>
<td></td>
<td>• Resistant to corrosion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 02) Glass Tile

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooring Tile</td>
<td>• Can be easily produced from waste glass.</td>
<td>• Its strength and water proofing characteristics need to be investigated</td>
<td>• It is used as a decorative floor tile</td>
</tr>
<tr>
<td></td>
<td>• Glass can be recycled without using much energy as used in the conventional recycling process.</td>
<td></td>
<td>• Made from crushed glass with a bio-resin as the binding material</td>
</tr>
</tbody>
</table>

### 03) Plastic Floor Tile

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooring Tile</td>
<td>• Lightweight and durable</td>
<td></td>
<td>• Same product as the plastic wall tile</td>
</tr>
<tr>
<td></td>
<td>• Resistant to water</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The product is protected by flame retardants</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 04) Paper Tile

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooring Tile</td>
<td>• Can be easily produced</td>
<td>• Consistency of the product is hard to achieve from manual production</td>
<td>• Wheat starch paste is used as the binding material which gives the compressive strength of the product.</td>
</tr>
<tr>
<td></td>
<td>• Lightweight in Nature</td>
<td></td>
<td>• Fire resistivity is improved by adding borate compounds in the mixing mold.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Waterproofing property is achieved by varnish</td>
</tr>
</tbody>
</table>
### 7.3.4 ROOFING SYSTEM

#### 01) Cardboard Panel – ModRoof

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofing Panels</td>
<td>• Good heat, flame and water-resistant properties</td>
<td>• Any physical damage to the coating of the product will destroy the water-resistant properties of the material.</td>
<td>• The coating on the panel is important to keep the material waterproof. However, research is being made about how to make the inherent core material waterproof without the coating material.</td>
</tr>
<tr>
<td></td>
<td>• Durable in nature</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Light in weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Modular in nature and can be manually built</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Safe alternative to existing asbestos roofing sheet</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 02) Structural Plastic Lumber

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofing Joists</td>
<td>• Can be used as an affordable alternative to structural I-steel beams</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Resistant to corrosion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 03) Plastic Roofing Tile

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofing Panels</td>
<td>• Can be easily produced</td>
<td>• Durability of the product is unknown</td>
<td>• Made mainly from low density plastic and saw dust</td>
</tr>
<tr>
<td></td>
<td>• Resistant to water penetration and heat conduction</td>
<td>• Leaching effects due to ultraviolet radiation and high temperature need to be investigated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Good fire-resistant property</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Does not corrode unlike the existing metal sheets used</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The same building material from waste can have different uses as furniture elements. The main concern with the furniture products is their durability.

### 7.3.5 FURNITURE

#### 01) Paper Wood

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Can be made into boards used in furniture as table and chair tops, boxes</td>
<td>• Non-toxic in nature</td>
<td>• Water proofing is done by a finish of varnish or wax which if damaged may pose problems</td>
<td>• Made from newspapers</td>
</tr>
<tr>
<td>• Decking material for lofts</td>
<td>• Easy production can be done without sophisticated technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Dashboard for cars</td>
<td>• Workability like wood</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 02) Structural Skin

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Decorative finish or furnishing material</td>
<td>• Production can be done without sophisticated technology</td>
<td>• The adhesive used is bone glue and its effect to moisture or water needs to be considered</td>
<td>• Strength of the material need to be evaluated or tested depending upon the use in the furniture. The strength can be improved by reinforcing the slats with wood sticks.</td>
</tr>
<tr>
<td>• Slats or sticks which can be used as frames in furniture</td>
<td>• Non-toxic in nature</td>
<td>• Water proofing is done by a finish of varnish or wax which if damaged may pose problems</td>
<td></td>
</tr>
</tbody>
</table>

#### 03) Plastic Lumber

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ladder for vertical access</td>
<td>• Durable product</td>
<td>• Production requires technological research about the strength characteristics as well on the manufacturing machineries.</td>
<td>• The plastic used in the making of furniture should be safe to use and the possibility of long term leaching effects needs to be considered</td>
</tr>
<tr>
<td>• Frames for the lofts inside rooms</td>
<td>• Durability</td>
<td>• Production requires technological research about the strength characteristics as well on the manufacturing machineries.</td>
<td></td>
</tr>
<tr>
<td>• Furnitures like chairs and tables</td>
<td>• Durability</td>
<td>• Production requires technological research about the strength characteristics as well on the manufacturing machineries.</td>
<td></td>
</tr>
</tbody>
</table>

#### 04) Glass Tile

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantage</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass Tile</td>
<td>• Decorative surface material on furniture</td>
<td>• Made from crushed glass and solidified by using epoxy resin</td>
<td></td>
</tr>
<tr>
<td>• Lamp or lighting shades</td>
<td>• No durability concerns</td>
<td>• Made from crushed glass and solidified by using epoxy resin</td>
<td></td>
</tr>
<tr>
<td>• No durability concerns</td>
<td></td>
<td>• Made from crushed glass and solidified by using epoxy resin</td>
<td></td>
</tr>
</tbody>
</table>
### 7.3.6 OPENINGS

<table>
<thead>
<tr>
<th><strong>01) Cardboard Panel</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use</strong></td>
</tr>
<tr>
<td>Door and window panel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>02) Paperwood</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use</strong></td>
</tr>
<tr>
<td>Door and window panel</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
## 03) Plastic Lumber

<table>
<thead>
<tr>
<th>Use</th>
<th>Advantages</th>
<th>Drawbacks</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lintel and sill of windows and doors</td>
<td>• Durable and light</td>
<td>Leaching due to long exposure to sunlight or high temperature need to be investigated</td>
<td>• For use as lintel beam strength characteristics of the plastic beam needs to be investigated</td>
</tr>
<tr>
<td>Window and door frames</td>
<td>• Alternative to wood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sash, head and stiles of windows and doors</td>
<td>• Water Resistant</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 7.3.7 FINISH MATERIALS

| Materials                      | Uses                                                                 | Drawbacks                                                      | Note                                                                 |
|--------------------------------|----------------------------------------------------------------------|                                                               |                                                                      |
| Non-Metallic PCB as Cement Aggregate | • The non-metallic part of the PCB (Printed Circuit Board) act as an air entraining agent which makes the cement more resistant to freeze and thaw. | • There is a slight reduction in compressive strength. For a 10% mix cured for 28 days there is a 18% decrease in strength |                                                                      |
|                                | • It also improves the R-value of the cement material due to the air content of the cement |                                                               |                                                                      |
|                                | • Improves the water retaining properties of cement mortar          |                                                               |                                                                      |
Figure 7-1. Potential Applications of the Building Materials in the Housing (Source: Sourav Dey)
Figure 7-2. Diagram Showing Potential Applications of the Case Study Building Materials
This analysis presents different opportunities of re-use depending upon type of waste material used that the figure 7-2 summarizes. The materials made by melting the plastic seem to satisfy most of the needs of the inhabitants of the slum, but there is concern for its local production. The long term toxic effects of plastic products are also a concern. Due to the availability of various types of plastic products, building from plastic products can satisfy different needs of the housing for roof, envelope, tiles, and structural frames. The materials from cardboard and paper do not cause concerns about toxicity and are easy to produce. The paper and plastic products need additional layers of coating to protect them from water and fire. The sheet made from Tetra-Pak, which is used as a roof element or a wall envelope, is the most suitable product due to its good strength and thermal and water-resistant characteristics. It is also light and easy to build with. There is no concern with toxicity as polyethylene, which is a safe product, is the only plastic material used in the composite product. The production can be carried out locally but requires compression machines and space for installing the machine. In addition, the crushed glass recycling methods are mainly used for either aesthetic materials like tiles or as aggregates in clay to improve the material characteristics. The recycled leather product as mentioned in the study can easily be produced but its durability and strength characteristics need to be investigated. The electronic waste recycling in the slum needs to be regulated and conducted with proper equipment. The contribution of the people of Dharavi in e-waste to a building material is limited to the effort of supervised dismantling process in recycling centers as most of the recycling of electronic waste aims to extract metallic compounds such as copper and gold using chemical processes in a controlled environment. The non-metallic powder is a residue of the chemical processes, which can contribute to a building material by acting as an air entraining agent in cement.
Figure 7-3. Diagram showing the Existing use of Building Materials and the potential use of the Case Study Building Materials from Waste in place of the Conventional Materials (Source: Sourav Dey)
8. CONCLUSIONS

Dharavi has an established economy of recycling, but this economy cannot be termed circular. Though it has some benefits of a circular economy, this existing economy is performed at the cost of health of the informal laborers. The existing economy has the potential to transition to a circular building economy only if the safety of the workers is taken into consideration. This research outlines an overview of the possibilities of a circular economy from solid waste sources focused on building materials only. The case studies around the world provide references about what can be translated and adapted to the Dharavi context. The development of building products from the available waste resource addresses the following major challenges of the existing housing situation: the extraction of materials from a depleting finite pool of natural resources and the detrimental environmental impacts from the generation of waste. The research initiates the brainstorming process required for implementation of a circular loop by identifying the type of construction used in the informal construction and the potential building parts that can be improved or renovated by the type of building materials from waste. This research is focused more on the applicability of the waste building materials to small scale informal houses but presents with an opportunity for future study of factors influencing the applicability of these materials to the formal construction market. In this research on Dharavi and the waste, the research points out a potential entrepreneur or an organization about the obstacles, benefits, and the potential stakeholders to approach in order to organize the value chain of this building industry from waste.

From the study, it can be concluded that most of the building products from waste that will be most useful for the needs of the informal and the formal market need the aid of sophisticated technologies for manufacturing. The Tetra-Pak board, cardboard roof panel and the plastic bricks are products that hold the most promise to suit and satisfy the needs of the people of the slum of Dharavi. Out of these three products only plastic bricks can suit the demand of the formal market as the other two does not fit in the formal conventional construction method. The case study shows
that some of the furniture products from paper waste, cardboard, and glass can be safely produced with low cost technology and sold in both the informal and formal markets. The paper wood, glass walls, and the glass tiles hold the most potential to serve the formal and informal market, generating income in the process due to their easy manufacturing process.

Under the present conditions of the informal settlement of Dharavi, only a handful of building products that suit the informal needs, can be locally produced from start (via sorting processes) to finish. This holds true for most of the other urban informal settlements. For the building products made from plastic and e-waste, further research needs to be conducted to establish a circular model. Dharavi already has an established circular model, but it is a very crude model which can be improved by certain actions of the various stakeholders involved in the economy. The informal market is not a segregated market. It depends upon the consumers of the formal market of the city of Mumbai, which again links to the companies who manufacture the products to cater to the market of the formal city. The transition to a circular economy of building materials would take time as establishing a loop would not happen overnight and alternate actions need to be figured out to safeguard the people from any harmful effects involved in the recycling business. The burning of chemical cans and disassembling electronic waste exposes laborers to harmful toxic liquids, gases, and metals. Toxic activities like these need to be identified and tackled responsibly one by one.

The production of most of the building materials require heavy machinery as well as technological knowhow. The involvement of various non-profit organizations, the research institutes, as well as educational institutes will be necessary to identify the type of labor and financial support necessary to conduct the recycling process and to educate the people in the informal housing areas about the possible steps that they can contribute to the production process. Designers also need to redesign the process so that the extraction of materials after their first use is easy and can be fed into another loop sustainably without having any negative impacts. With the existing waste production, research is needed to identify the consumer products and which parts of the material of the product can be recycled or extracted. Involvement of chemical
and material scientists is necessary to figure out the ways to disassemble the composite materials to be further re-used identifying any potential risks associated with recycling of a product. A concerted effort from designers, manufacturers, as well as the consumers is a necessity. Moreover, for the products to capture the market, a demonstration of the use of the products is essential both in the formal and the informal housing areas.

Moving towards a circular economy is an action that is essential for solving global environmental and economic challenges. The approach is an opportunity where economics and profitability meet sustainability. One of the barriers of the circular economy going mainstream is an insufficient business case. The financial benefits for supply chain players in a circular economy must be equal to or better than what is possible with the conventional model of brand new products being made to replace broken or obsolete items (Hower, 2016). The other barrier is the increased education effort needed to make a successful case to mobilize the consumers and the manufacturers. In the report, The Circular Economy - Connecting, creating and conserving value by the European Commission (European Commission. Environment Directorate-General, 2014), stimulating the circular economy requires extensive policy support at national, regional and local levels.

Many of the case studies on building materials from waste present us with important contextual issues that cannot be neglected. The applicability of the circular process requires an adaptation of the model to the specific context. For example, in the case of the plastic bricks by Oscar Mendez in Colombia, the houses are made on open fields and there is no required rigidity in the dimensions of the bricks. Thus, longer bricks may serve the purpose but the same long brick dimensions may not be suitable in the case of Dharavi, as the houses are not built afresh but are renovated or repaired on existing structures with a limitation on the availability of space. In order for a successful model to be developed, the raw materials need to accrue to a promising amount to be turned into a successful business. An efficient collection system is required to be established for establishing a successful economy of building materials.
Different laborers work informally collecting and sorting different types of waste products in the slum. There is no organized information about the amount and type of the solid waste that flows in and out of the slum. A common information exchange platform will help traders and recyclers to inform each other about the type of product and the bulk that is available. Since production of a building product requires a vast supply chain of raw materials, a common information exchange platform would be beneficial to bring all the materials together to be fed into the building production loop. The Digital India initiative has enabled the people to have cheap access to the internet through smartphones. Following the parallels of the e-commerce web portal named Dharavi Market, a web-based information exchange platform about the waste materials collected would be beneficial. Individual recycling units having different products could negotiate a fair price with the manufacturers. In conventional businesses, Dharavi involves a lot of middlemen who use their buying power to coerce the craftsmen into selling their products at a lower price. The products are passed through a circuitous supply chain to finally reach the end user who had to bear the hidden costs of the supply chain (Narasimha, 2017). The presence of middlemen leads to exploitation of the workers who get paid less and are subject to the whims of the fluctuating prices.

The contribution of the informal economy in Dharavi is not recognized by the government, and thus it does not receive the infrastructural support required for it to function efficiently without risking the health of the people working there. Most of the businesses in Dharavi are unregistered as they fear taxes from the government. Thus, they are considered black-market businesses, which leads them to be exploited by the inspecting police for bribes to let them run their businesses. The unrecognized nature of the businesses hampers the possibility of them to get a decent price for their products and hinders obtaining financial support from the banks, which could improve the infrastructure of recycling and make it more efficient. Walter R. Stahel (Stahel & Reday-Mulvey, Jobs for Tomorrow: The Potential for Substituting Manpower for Energy, 1981), the founder of the circular economy philosophy, points out that the transition of a service-based circular economy
should be incentivized, and this incentivization could be achieved through the non-taxation of renewable resources such as labor, human work wages and taxation of the non-renewable sources.
BIBLIOGRAPHY


Central Pollution Control Board. (2015). Brick kilns in India. New Delhi: Central Pollution Control Board.


REMATERIALS. (n.d.). REMATERIALS.


The Story of Stuff (2007). [Motion Picture].


UN Habitat. (2015). Slum Almanac - Tracking Improvement in the Lives of Slum Dwellers. UNON.


