Waste as a Building for Slums in Developing Countries

Possibilities of waste as a building material for slums in developing countries.

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Abstract

This research is driven by two common problems in large highly populated urban areas: waste management and housing condition. The main goal is to effectively make use of the available waste and improve the houses in poor urban areas, slums. In this research a solution is explored by developing a product made out of waste which satisfies current needs for slum houses.

Waste problems occur all around the world, but the sort of waste differs per type of country. Least developed countries consist of a high percentage of organic waste, while within more developed countries the percentage of organic waste is much lower. Furthermore, developed countries produce much more waste than these least developed countries. Therefore the amount of organic waste in developed countries is higher, compared in absolute figures. Most of the developed countries have a waste management industry and are therefore able to control their waste; while the poor developing countries are not able to treat their waste. This shows that the consistency of waste might differ in countries, but because of the extreme amounts, every type of waste is abundant. A new type of industry needs to be created to reprocess the waste into useful products.

The reviewed literature shows a wide variety of waste products, manufactured by two different approaches, high-technology and low-technology. For both it is important to process the waste in several steps, with the following three main steps:

1. Sorting process
   The sorting process is important to collect waste and separate different materials out of the waste stream. As a result, valuable materials can be sold and old the other waste can be treated with specific processes for its material.

2. Preparation process
   During the preparation process the material is prepared for the production phase. Most of the time this process consist of cutting, cleaning and drying the waste.

3. Production process
   During the production process the material is processed into a new product which can be done by high- or low-technology.

In order to decide whether a high-technology or low-technology production process is the most suitable, the demand and needs of a slum area must be defined. Currently, slum inhabitants are able to create a structure for their houses, where corrugated steel sheets/panels are used to cover the façades and roof surfaces. These corrugated sheets are easy to overlap on each other on existing structures, showing bad insulation properties, noise and thermal. Therefore a new waste based product should bring an improvement to the current corrugated steel panel. Social aspects such as high criminality rate and no stable income, play an important role in slum areas. In order to apply a new product, inhabitants should be involved in the production process. By generating not only an improvement for their house, but also an income.

Eight existing products are evaluated by an assessment method that makes judgements on different alternatives taking into account several criteria, based on the demands and needs of slum areas. This assessment method is known as a multi-criteria analyses, MCA. The MCA is applied to show the differences of both type of production processes, high-tech & low-tech. Scores are given to them, in order to determine which type of production process will be more suitable for slum areas.

The low-technology production process is more suitable for slum areas. Inhabitants can be involved with the production and with simple tools it is possible to create high quality products. High-technology production processes need more investment and the products will be too expensive for slum inhabitants. Basically, costs influence the success of the product and therefore the costs need to be kept as low as possible.

The analyses of existing production technologies for different types of panels, showed the quality of the panels is mainly influenced by the binder. Some of the binders are defined as toxic. These binders give good strength and prevent the panel to degrade. It is also possible to use bio-based binders, but these binders are still under development. All these ‘panel binders’ will increase the production cost. In order to create a feasible product for slum areas, it is desirable the binder is a type of waste itself.
Some waste materials, such as metals and glass, have a complex high temperature recycling stream. Therefore, the panels can be made out of a combination of plastics, organic waste and paper. After producing different types of samples, it was observed that plastic can be melted and mixed with organic waste and paper. After cooling down this product, the plastic will go back to a solid phase and the organic waste and paper is bound within the plastic.

Several factors influence the binding between plastic and other materials, the percentages of the materials, production temperature, pressure and time. The best outcome of all the samples is a panel made out of 50% dried waste combined with 50% pure PET, PP or PS plastics. Those plastics come out as the best options, based on their properties, availability and low toxicity. The mixture needs to be heated up with a temperature suitable for the plastics to be melted. The production time depends on the size and thickness of the panel.

Two types of moulds are used to create the panels. One mould creates the connection strokes and one mould creates the standard panels. The connection strokes enable the gradual substitution of the current corrugated steel panels. An additional feature of the product, is that an optional insulation layer can be applied. A double layer of panels will be applied with a layer of dried waste in between. This insulation layer can be applied after a few years, or immediately.

The production process creates labour for slum areas, accountable for the drying and cutting process of organic waste. The plastic will be treated by sorting, cleaning and grinding processes. A small simple low-technology press is designed, which makes it possible to heat up the mixture and apply pressure with simple screws, based on old wood laminating machinery. After the production process, the panel is ready to be used.

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This master thesis is a result of a research and serves as a completion of the Master track ‘Building Technology & Product Development’ of the faculty Build Environment at Eindhoven University of Technology, the Netherlands.

The topic of waste is chosen out of own interest. Waste is everywhere and in a western country as the Netherlands, waste is thrown away without being aware of the consequences. Media shows problems of waste but because people are not affected on a daily basis, it also does not create awareness of using materials more carefully. After a small research showed the urban poor of mega-cities are affected the most by our daily waste. Those people try to survive by selling waste for an income or using waste for their own houses. Therefore this report links those two topics by creating a high-technology product made with useless waste materials for the urban poor.

First of all I would like to thank my supervisors from TU/e: Jos Lichtenberg, Roel Gijsbers and Tim de Haas. They kept me motivated and focused with their feedback during several meetings. Without their knowledge and positive feedback, this research would not have reached its quality.

Second of all, I would like to thank PHD-student Harm Caelers, who let me work with a pressing machine in the Polymer Laboratory of Mechanical engineering. Without his enthusiasm, I would not have been able to create different samples of the material.

Also these samples could not have been made without the plastic given by different companies. Therefore, I would like to thank all of these companies: ‘Plastic Herverwerking Brabant’ (P.H.B.) te Waalwijk in corroporation with ‘Van Gansewinkel’, ‘plastic recycling company’ te Schijndel, en Waste processing company ‘Attero’. Attero not only provided plastic but also gave a tour through their waste-to-energy plant in Wijster. This tour, given by Peter Bakkers, was very useful because it gave insight into the possibilities of waste treatment and the problems which even occur in high technological companies.

I would also like to thank Benny Luijsterburg for his information. Benny is a PHD-student from the department of chemical engineering for the group, Polymer Technology. He explained some theoretical problems with the recycling of plastics. This information helped a lot during the sample production, because it became clear why some combinations of plastic and waste do not work together.

Finally, I would like to thank my family and friends, who supported me with patience throughout the whole process. Their positive energy motivated me during this graduation project.

Karlien van der Linden
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This chapter reviews the problems associated by rapid urbanization, change of living standards and growth of municipal solid waste. Which are the main drivers for this research work.

1.1 Motivation

1.1.1 Growth of waste & urbanization

The demand for goods and services rises rapidly, as the result of world population growth, booming economy, rapid urbanization and the rise in community living standards. All these factors have greatly accelerated the municipal solid waste (MSW) generation rate in the world. (Minghua et al., 2008)

The amount of municipal solid waste is one of the most important by-products of an urban lifestyle, which is growing even faster than the rate of urbanization. Ten years ago there were 2.9 billion urban residents who generated about 0.64 kg of municipality solid waste per person per day (0.68 billion tonnes per year). Today, these amounts have increased to about 3 billion residents generating 1.2 kg per person per day (1.3 billion tonnes per year). By 2025 this will likely increase to 4.3 billion urban residents generating about 1.42 kg/capita/day of municipal solid waste (2.2 billion tonnes per year). (Hoornweb & Bhadata, 2012) This amount of waste need to be controlled by a waste management system. The reasons for waste storage and sanitary disposal and the technology of waste landfilling are well accepted and understood in developed countries. Developed countries have established regulated programs for the disposal of solid waste, while developing countries have generally continued to use unsophisticated methods such as open dumps. The waste disposal in developing countries is random and uncontrolled and large quantities of waste go uncollected. (Al-Khatib et al., 2006)

Furthermore, developing countries face a daily problem of the fast growing and poorly planned urbanization. Together this creates unhealthy living situations due to the lack of basic services, such as drinking water, sewage system and a waste management system.

This report aims to find a way to use MSW of the urban lifestyle in developing countries in an alternative way. Waste can become of a high value when applied as a building material. On a low tech level, the inhabitants of developing countries already use waste as a building material. For example in Africa there are places where people built buildings made out of plastic bottles. (Laylin, 2012) Another low tech example, are houses made out of car tires in Haiti (Meinhol, 2010) or roof tiles made out of old plastic bags. And also the water bottles filled with chlorine to create a daylight system in slums. (Laylin, 2011 Inhabitat)

Waste can also be applied as a high tech material. The difference between a low-technical and high-technical material is the amount of industrial resources involved in the production process. For example the recycling process of concrete is a high-tech system. The concrete is processed in different steps of crushing, pre-sizing, sorting, screening, cleaning and contaminant elimination. A high quality concrete is the final product. (recycling process of concrete, 2011) There are also examples of products that are a high-tech solution in the way they are developed. But the final use is completely low-tech. For example the Heineken ‘Bottle brick’.

Dutch architect John Habraken designed together with Alfred Heineken a ‘brick that holds beer’. The beer bottle can be used as a brick when the bottle is empty. The idea of this ‘Beer-brick’ got its origin after noticing two problems in the Caribbean, beaches littered with bottles and a lack of affordable building materials. (Kriscenski, 2012 Inhabitat)
1. Introduction

1.2 Problem outline
In the world there is a grow of population, rapid urbanization, grow of cities and industry and an increase of living standards of human beings in developing countries. This all together creates a grow of waste and mega cities. These mega cities cannot cover the demand for proper housing and the adequate management of solid waste. The problem outline can be defined as: ‘The amount of waste and the need for proper housing in mega cities of developing areas are growing’. In order to define this problem further, solid waste management and the need for proper housing in developing areas are described.

1.2.1 Solid waste management, SWM
Waste has vexed civilization for thousands of years. After the industrial and petrochemical revolutions, waste concerns have grown exponentially. Before, there were open dumps and there was a lack of substitutes for dangerous products and pesticides. These open dumps had slowly led to air and water pollution that affected millions of people in developed nations and continue to be a problem in developing nations. (Letcher & Vallero, 2011)

Waste is discarded by an individual, household or organization. As a result waste is a complex mixture of different substances, only some of which are intrinsically hazardous to health.

According to the ‘World Bank’ the higher the income level and rate of urbanization, the greater the amount of solid waste produced. Income level and urbanization are highly correlated and as incomes and living standards increase, consumption of goods and services correspondingly increases, as does the amount of waste generated. (Hoornweb & Bhadata, 2012)

The income level and rate of urbanization does not only have an impact on the amount of waste but also its consistency, figure 8. Because of the huge amount of waste, a SWM is necessary to control these amounts. Though this SWM releases emission which are a threat for water pollution, air pollution and eventually for physical health. (Rushton 2003) This pollution creates problems for the entire world. Even though most western countries are able to control their SWM in a safe manner, the growing waste of developing countries is increasing the worldwide pollution. The urban areas from these countries are dealing with the consequences. The urban areas cannot control their waste and therefore most of the waste ends up in dump sides which can affect the entire water system of the city. (Rushton 2003) (Hoornweb & Bhadata, 2012)

Another problem is the growing electronic waste which from all western countries is chipped to Africa and Asia. Electronic waste is one of the major waste problems. At the moment there are open dumps full of electronic waste. The challenges in dealing with these open dumps full of so-called e-waste continues to multiply because the market for electronic products keeps expanding as countries cross the so-called ‘digital divide’. (Kuehr et al., 2011)

This e-waste is a problem because its contents of toxic and valuable materials. Developing countries are removing these valuable metals by melting the plastic and eventually burn the plastic out of the metals in an uncontrolled environment. The high toxicity of the pollutants are emitted in those moments. (Widmer et al., 2005)

Therefore, the people who work on these open dumps are daily exposed to high toxicity of the metals, burned plastic and the pollutive liquid in some electronics.

Figure 3; Export of e-waste © Greenpeace, Basel Action Network
1. Introduction

1.2.3 Problems developing countries

First of all, it is important to first define the term developing countries. The world bank creates a scheme of the world based on an income level which include following: Low-income countries, low-middle income countries, high-middle income countries and high-income countries. Unfortunately this scheme does not include living standards and economic growth of countries. That is why a different separation of the world is used. The standard & poor’s index data platform divides the world in emerging countries (newly industrialized countries), the developed world and the developing world. Because in this way the developed world consist of too many differences within income and living situation also the term of UN Statistics, Least developed countries (LDC), is used in order to create four different types of countries. Eventually all the data per country from United Nations and World bank is used to have clear data per country and to create average numbers per each type of country.

As seen in figure 4 the developed world is relatively very small and most of our world exist of developing countries. These developing countries are growing in several ways. The population level is increasing, a booming economy and together it causes a rapid urbanization. This all creates opportunities for developing countries but it is also facing a lot of problems for the majority of low-income households. (Bredenoord & Lindert, 2010) According to UN-Habitat, between 2010 and 2015 almost 200,000 people will be added to the world’s urban population each day. (UN Habitat, 2012) The developing countries have a divergent urban growth pattern. In the last decade, the population in the developing world grew an average 1.2 million people per week. (UN-habitat, 2012)

This expansion of the world habitats creates dense cities, mega-cities, where it will be a challenge to accommodate their citizens. This means that all these mega-cities should provide houses as soon as possible for those without an accommodation. Nevertheless providing houses is not just the problem. Governments should improve the current living situation of existing slums and try to prevent future illegal slum areas. The housing conditions of slums faces a lot of problems: unsafe water supply, inadequate housing and services, poor sanitation and are in unsafe areas of the city. (Bredenoord & Lindert, 2010)

The population in slums is growing the most rapid of all populations in developing areas. Because slums are not planned in cities, they keep expanding. The living situation is becoming more dramatically every year. There is no water supply and mostly one toilet per 20 households. This increase of urban populations in developing countries creates also an increase per capita generation of municipal solid waste. (Minghua et al., 2008)
1. Introduction

Not many restrictions and rules are applied by the government while open dumps still exist in these countries. These open dumps pollute water, this pollution is increased in slum areas and eventually pollute the entire water supply of cities. (Hustwit, 2011)

In order to improve the development of cities and the housing conditions, it is necessary to nationally reform various aspects of decentralization, like: revenue allocation, community participation, local elections, local planning and pro-urban development strategies. This decentralization has not been successful because there is a mismatch between responsibilities and financial resources. In the past, various developing countries have been in a conflict, political instability or an economic crisis. The governments are still recovering of these factors while the responsibilities of municipal governments have increased in recent years. They do not have access to the financial resources needed to undertake action. (UN Habitat, 2012)

1.2.4 Problem definition

Waste and the housing situation in developing areas have a great impact on the current global health. At the moment there is a global waste problem and the current solid waste management is pollutive. The population in the world is increasing which creates a lot of problems especially in the newly industrialized developing countries (NIC)/emerging countries. In these countries the increasing population and increasing industry are increasing inhabitants in cities. Poor people from agricultural areas are moving towards cities to search for jobs and with the idea of improving their lives.

The governments cannot control this growth which creates an high demand to proper housing for the poor urban population. Therefore they end up in slum areas where they built there own dwellings. The current housing conditions for these poor urban population in slums are in bad and dangerous condition. There is bad sanitation, dangerous water supply, corruption, unsafe areas and a waste problem because of the missing solid waste management in slums.

The waste is polluting the water supply not just for the slums but also the entire city. This polluted water supply is very dangerous for the health of all inhabitants. Another problem in the slums of industrialized developing countries, is that mostly the slums are built nearby open dumps. A lot of electric waste from the western world is sold to newly industrialized developing countries. There the poor urban population is collecting the valuable metals out of this electronic waste in very unhealthy circumstances. In order to this they earn an income and can effort themselves some basic needs like food. There is mostly not enough income to improve their home or money is not invested because of the uncertainty whether or not the government will allow them to live in the area. This means, the growth of waste and population creates dangerous and unhealthy living situation of urban poor near by open dumps sides in cities.

Problem field: global waste problem and a need for proper housing in slums in newly industrialized countries.

Figure 5; Growth of waste & megacities
Figure 6; Slums arrange their own systems
1. Introduction

1.3 Research objective

1.3.1 Objective
This research is driven by two common problems in large highly populated urban areas: waste management and housing condition. The main goal is to effectively make use of the available waste and improve the houses in poor urban areas, slums. The goal within the research is to explore a solution by developing a product made out of waste which satisfies current needs for slum areas.

1.3.2 Research question
Based on the problem definition and the objective of this study, the research question can be formulated as follow:

In what way is it possible to use waste as a building product for slum areas in newly industrialized countries?

In line with the research question, some sub questions can be formulated. Answering these sub-questions should lead to the development of a product that fulfils the answer to the main question.

1. What is the meaning of waste?
   - a. How is waste management organized (SWM)?
   - b. What is the composition of the waste in every type of countries?
   - c. What is the effect of waste/problems?
   - d. What are the current waste up-cycling/recycling production processes (state of the art)?

2. What is the current technical condition of houses in slums?
   - a. How is the technical state of houses in slum areas?
   - b. How are slums organized (legally, corruption etc.)?
   - c. How are current upgrading programs organized? (Corruption, governmental, organizations etc.)

3. In which way can waste be applied as a building material?
   - a. In which way can waste be applied as a low-technological material or high-technological material? (state of the art of slums/materials etc.)
   - b. What kind of waste material is suitable for low-technology up-cycling processes?
   - c. How can a material be produced out of waste?

4. In which way is it possible to create a product out of waste material?
   - a. What are the boundary conditions of the product?
   - b. What are the needed production processes to create a suitable product?
   - c. How can the product be applied for slum houses?

1.4 Research relevance and contributions
The research is relevant to society because the future growth of waste is increasing the global waste problems. Simultaneously, the growing population in cities creates a demand for houses. The current cities cannot meet this demand, resulting into a growth of poor living conditions for inhabitants. This research is of significance to these future citizens by using alternative building materials to create a healthy and safe accommodation by themselves. The thesis is also of scientific relevance because it is a first attempt towards an investigation to alternative building materials, waste, for sheltering application.

In total the innovation of the entire graduation project is the development of a low-tech recycling process. At the moment most recycled products are produced on large scale with high technology machinery. This project on the contrary tries to develop a product made with simple tools on a small scale in order to create an income for poor urban areas, without losing the technical quality of the final product.
2. Research Methodology

2.1 Research model

Figure 7 shows a visualization of the research model that consist of a literature study and a design part.
2. Research Methodology

2.2 Research Method
2.2.1 Literature study
The first step in this literature study is to define the concept of ‘waste’ in development countries’. The second step will be a research on the current waste management in developing countries, waste being used as a product and the current situation of housing in slum areas.

After this research, the needs for slum areas and possibilities for waste materials can be defined and translated into a conceptual material.

2.2.2 Conceptual Material design
As an outcome of the literature review, a material for the product is created. Several production techniques are analysed in order to define a production process suitable for the targeted waste material.

2.2.3 Sample production and testing
The conceptual production process is carried out at a laboratory scale obtaining samples. The sample production process is done with simple tools. The pressure, temperature, time and ratio of the waste materials is defined. Several tests are applied to check the potential success of the material and its performance.

2.2.4 Product and production development
As a conclusion of the sample production and testing, the material is developed into a conceptual product. The needs for slum areas are fulfilled by creating a suitable product and production process for the areas. During this product development several factors come together which are defined during the literature study.
3. Waste management

3.1 Waste management

3.1.1 Waste

Waste is defined as anything which is eliminated or discarded as no longer useful or required after its useful lifetime. It is an unwanted or unusable material, substances, or by-products. This definition makes it even more complex. This means that waste which can be recycled or up-cycled is not waste anymore but a valuable product. Therefore, the definition of waste needs to be defined more precisely. Waste is an unwanted material discharged to, deposited in or emitted to an environment in such an amount or manner that causes a harmful change. This means waste itself can be useful for another product or process, but because of the amount eventually it becomes a harmful threat. Waste is mostly a by-product of consumer-based lifestyles which drives most of the world’s economies. That is why it is important to separate two different waste generations. Waste generated by households and waste generated by commercial and industrial premises (institutions such as hospitals, industries, schools, offices etc.) This research focuses only on waste generated by households.

Rural areas got a much lower waste generation because residents are mostly poorer, purchase less store-bought items and have a higher level of reuse and recycling and mostly control their own waste by for example burn some materials. Therefore solid waste is in general considered as an ‘urban’ matter. To control waste, solid waste management is applied globally over the last 40 years. (Tibajuka et al., 2010)

Solid waste management is most of the time the responsibility of local governments and in developing countries it is often their single largest budget item. To manage all the municipal solid waste, municipalities need capacities in procurement, contract management, professionals, expertise and an operating budget and finance. Municipal solid waste also needs a strong bonding between the municipality and the inhabitants. (Hoornweb & Bhadata, 2012)

3.2 Solid waste management

Solid waste management is the treatment and systematic control of waste through different processes. These processes are:

- Generation
- Collection
- Storage
- Transport
- Source separation
- Processing
- Treatment
- Recovery
- Disposal of solid waste

Generation

Municipal solid waste, MSW, is influenced by economic development, degree of industrialization, public habits and local climate. Therefore, MSW generation differs by region, country, city and even within a city. (Hoornweb & Bhadata, 2012) These factors are described in Appendix 1.2. Figure 1, appendix 1 shows that Newly industrialized countries generate the most amount of total municipal solid waste per kg, per day. Developed countries generate the most amount waste per person, but because the high population of Newly industrialized countries is much more, they end up with the most amount of waste. The composition of waste is influenced by the generator, and therefore varies widely. It is influenced by many factors, such as: level of economic development, cultural norms, geographical location, energy sources, climate and seasons. (Tibajuka et al., 2010)

Figure 2 of appendix 1.1, show a comparison of the waste composition in each type of country. It shows, least developed countries produce the most organic waste in their own waste generation. But it the exact numbers are compared, all the other countries produce more waste. It even shows, the majority of municipal solid waste consist out of organic waste followed by other, paper, plastic, glass and metal.
3. Waste management

Collection
The collection system is an important element of solid waste management. A collection system must be designed and operated for the ultimate goal of the waste. Which means if the waste will be recycled the collection stage has to be different than if the waste will be deposited at a landfill. To understand the entire collection system and options it is important to separate some elements: when the collection takes place, where the collection takes place and how this process goes. In general the municipal solid waste collection consist of a 'vehicle' as the main factor. But this vehicle can be very low-tech, an animal, or high-tech, a truck designed to pick up waste. Appendix 1.3 explains all the aspects of collection, its transportation and the different ways of storage. (Coffey & Coad, 2010)

Source separation
The separation of waste is applied different in each country, area and situation. The main goal of source separation is to sort waste in order to separate all the valuable and recyclable material from waste such as glass, metals, paper, plastics and chemical waste. This is done to have a more efficient recycling process and to create a more organic final waste disposal. (Capel, 2013)

In order to minimise the degree of contamination of recyclables, the separation of recyclable material from mixed waste should be done as early as possible in the solid waste management chain. For example it is more efficient to sort waste for recycling at a transfer station than at a disposal site. Transfer station are smaller and trucks will come to pick up the waste. This means less material needs to be transported to the landfill and for the recycling quality all the clean waste can be separated from the wet polluted waste. This does mean more space is needed at the sorting station and the transportation needs to be better organized.

Basically there are six methods which can be used as a separation technology. Still a lot of machines are developed but mostly they use the same methods as described as following:

- Trommel separators/drum screens: machine which separate materials according their particle size.
- Eddy current separator: machine which sort metals out of waste through electromagnetic field.
- Induction sorting: machine with sensors which can locate different types of metals and are able to separate them by a system of air jets which are linked to the sensors.
- Near infrared sensors (NIR): machine which can distinguish different materials based on the way they reflect infrared light.
- X-ray technology: with x-rays it is possible to identify different types of waste based on their density.
- Manual sorting: a traditional technique which is still used today. It is possible to manual sort waste without any machines. Or waste is sent along a conveyor belt, so-called manual picking lines, where workers are sorting by hand. (Coffey & Coad, 2010) (Capel, 2013)

Figure 8; Waste composition in each type of country © Hoornweb & Bhadata 2012
# 3. Waste Management

Waste can be sorted into its material, colour or function. Mostly waste is collected by its material and colour to create an easy recycle stream. For some materials it is easy to recognize them and this can be done manual or by machinery. For example glass, paper, organic waste are easy to recognize. But for materials as plastic and metal it is more complex to separate these materials in their specific type of material. For example different types of plastics can be recycled. But in order to recognize each type of plastic, symbols are created which are printed on the plastic to identify them. This specific number refers to which plastic recycling material they can be reused. Appendix 1.5

## Treatment

In general there are three types of waste treatment technologies:

- Mechanical: recovery of solid waste like recycling, up-cycling, re-using
- Biological: anaerobic digestion, alcohol/ethanol production, biodrying etc.
- Thermal: combustion, gasification, pyrolysis etc.

An example for a mechanical treatment is waste recovery. Waste recovery uses waste to replace other non-waste materials to achieve a beneficial outcome in an environmentally sound manner like recycling. The chemical composition is not changed but the material or product is re-used or treated into a new product to prevent waste of useful material. Materials to be recycled are either brought to a collection centre and eventually sorted, cleaned and reprocessed into a new material. Paragraph 3.3 explains different waste recycling processes.

An example for a thermal treatment is incineration. Incineration converts solid, liquid or gaseous combustible wastes into ash, flue gas and heat by a burning process. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulate carried by the flue gas. (Tibaijuka et. al., 2010)

## Processing

The process is a part of the treatment and the processing facility is a part of the solid waste management and is the handling process after collection and separation. It includes treatment, transfer, cleaning, shredding, grinding, baling, salvage, de-water, reclaim and/or provide storage or processing of solid waste. It is more or less the preparation of a next phase for waste. If the next phase is a recycling process than in this process the waste will be cleaned and ground or even melted. Paragraph 3.3 explains these processing techniques for different recycling processes.

## Disposal of solid waste

After treatment, if necessary, the waste can end as a product like following:

- Open dump-site
- Landfill

A landfill is more or less a controlled closed dump-site. It is meant to cause minimum impact on the environment and a minimum cost. The site has to be managed and there are even different stages in the entire landfilling process.

- Site selection
- Site preparation
  - Solid waste is places, compacted and eventually covered by soil.
- Operation

![Figure 9: Landfill (adapted from Collection of MSW in developing countries 2010)](image-url)
3. Waste Management

3.3 Recycling processes

Recycling starts during the collection and storage process. Safety, the protection of the environment and resources are the main priorities in the recycling process. Materials that are very common to recycle are: glass, paper, plastic, metal, textiles and electronics and will be explained in this paragraph. Basically all the materials have gathering process, sorting process, preparation process and eventually production. It depends on the material how detailed each process needs to be done. Though for example glass recycling does not consist of many steps but the energy needed to heat up the material to its melting point is extremely high, 1100°C. Below all the production schemes are showed with an explanation.

Glass

Figure 10; Glass recycling process

Glass is an old product made of simple material. Glass is made out of sand, soda ash and limestone and that is why it is an easy recyclable product.

After the collection and separation process of waste, glass is brought to recycling centres. There the glass is sorted by colour manual or by special machineries. This is done in order to separate coloured glass from each other because of their different melting points and chemical incompatibility. Next step is cleaning and crushing the glass in small pieces, so-called cullet. (United States Environmental protection agency, 2013) (appendix ..)

The cullet is brought to a manufacturing plant and mixed with silica sand, soda ash and limestone. This mixture is melted in a furnace into a molten state. This liquid is poured into a molds and shaped/cooled into its new product. (United States Environmental protection agency, 2013)

Paper

Figure 11; Paper recycling process
3. Waste management

Recycled paper is very common and mostly western countries separate paper for years from other waste in order to recycle it. In other countries all type of waste is collected together and eventually the paper is separated from the waste and brought to recycling centres.

First the waste paper needs to be sorted by its different type of paper. After this separation, the collected paper is pressed together into bales in its own gradation. The bales are transported to paper manufactures, where the paper bales are soaked in vats with chemicals, non-ionic surfactants and dispersant. This way the paper is disintegrated into fibres, so-called pulp. The next process is the de-inking process, the printing ink will be detached from the paper surface and all the released ink has to be removed from the pulp. This can be done by flotation or washing. (Appendix, Paperacademy 2012)

After the de-inking process, the paper pulp is bleached and again mixed with water. After this procedure the fibres are made again into paper. This recycling process can be redone more or less seven times with the same fibres. With this process there is always a paper pulp waste. Some fibres are not high quality fibres, mostly because it is recycled already too many times before, and become the waste product of the paper industry.

Plastic

Plastic consist completely of raw materials including petroleum and crude oil. This is what makes a recycle process of plastic more complex and it produces more emissions than the recycling process of glass. Plastic waste is brought to plastic recycling plants where it is collected and eventually stored in large storage places. The more accurate and efficient the identification, sorting and separation is done. The better the quality of the recycled plastic will be. This identification can be done manual or by machinery described at source separation.

After the separation the plastic is cleaned to remove dirt, glue and paper. The washing process is different for each type of plastic. For example PET streams are washed around a temperature of 90 °C for 15 minutes, while the HDPE must be washed below 40 °C to prevent discolouration. The washing temperature is lower because of its lower melting point. (Wansbrough & Yuen)

After the washing process, the plastic is cut to reduce the size of large plastic objects. And eventually shredded into small flakes. This can be done by a chopper, which is a cylinder of blades which cut the material until it is small enough to fall through the grill.
3. Waste management

Clean film sheets are different processed then shredding the materials but with agglomeration. An agglomerator chops the film sheets into thin film flakes which are heated until they melt and form crumbs of agglomerate.

After the washing and chopping process, the agglomerates and flakes are separated in a flotation tank. These flakes are dried and then melted in a liquid. This liquid is fed through a screen for cleaning the finest particles out of the plastic. The plastic comes out in long strands, string out of the cleaning machine. This is cooled and cut into small pellets. This entire process is a so-called pelletizing process. (Wansbrough & Yuen) These pellets can be sold to plastic manufacturers in order to create new plastic out of the pellets. (van den Berg, 2009)

Any type of metal can be recycled because metals do not lose any of its physical properties during the recycling process. This is why the metal recycling processes can be done over and over again without losing its quality. This recycling process is explained by explaining the scrap metal recycling process. Scrap metal is basically any type of discarded metal which is suitable for recycling.

After the collection metals are separated from waste by magnetics or manual, which is sometimes a complex process and only done with aluminium cans because they are light and easy to collect and separate. After this separation the recycling process begins. (Hartman et al, 1999)

Scrap metals are brought to sorting agents. These companies separate the scrap metal by type and composition. The sorting agents sell or bring their separated metals to a metal recycling plants, which may be located on-site or at a different location. Before starting with all the processes, the metal recycling plant inspects the quality of the scrap metal it receives. This is done to be sure the sorting agent has correctly separated the metals. After the check-up, the shearing process or crushing process begins. Shearing is done with thicker scrap steel. Shearing means cutting and pressing with a hydraulic machine. The metal is cut in pieces of 60 or 80 cm.

Shearing is done to make it easier to handle with large metal objects. (Hartman et al, 1999)

The crushing process is done for various metals other than thick scrap steel. The crushing process is used to break down scrap metal and cars into smaller pieces so that the different metals can be separated and the impurities are removed. Then again a sorting process of the metals begins.

After these processes the separated scrap metal is pressed together into bales. This is done to reduce the volume of the scrap metal.

After these processes all the different types of metal scrap are melted with their own specific melting point. Once the metals are fully molten, the liquid is moulded into ingots. Which is a metal melted in a shape suitable for further processing. For example aluminium ingots are made into new sheets to start a new aluminium production process.
3. Waste management

Textiles

Recycling of textile is very common in a low-technical process. Old clothes are being reused through reselling or donation for charity. What most consumers are not aware of is that it is possible to recycle clothes also with production processes. This type of recycling stream is getting more popular and feasible to apply as long as colours stay separated.

Clothing collection is organized by a number of commercial and charity organizations. These organizations sell the clothes that are not suitable for re-using to the ‘flocking’ industry. Eventually these industries mill-grade all the incoming material according to their type and colour. Colour sorting saves energy and avoiding pollutants because in the other processes no re-dying is needed.

After the sorting processes the shredding and pulling process begins. This means the textile materials are torn or pulled into fibres. After this process the carding starts. Carding is a mechanical process that disentangles, cleans and intermixes fibres to produce a so-called web of fibres for the production process. Carding is nothing more than moving surface together with fibres between it. The fibres are pushed parallel with each other in a web.

After the carding process the spinning process begins. The web is spun together into yarns which are suitable to use for weaving of knitting. After this process any kind of material can be made.

The spinning process is not always necessary, sometimes the fibre webs are compressed together for insulation materials or other purposes. (Bureau of International Recycling, 2013)

Organic waste

Organic waste is in most countries dump in open landfills or created into compost, biological treatment. Like seen at the visit of Attero, appendix 7, is that this compost process is very easy as long as the collection of organic waste is separated from the other waste.

All the organic waste is checked on metals and bricks. After this check-up the waste is chopped into pieces of 10-15 cm. The organic waste is stored for four weeks in a building under moisture properties. The moisture influences the compost process, by applying carbon/nitrogen/oxygen and hydrogen. During the storage time, the waste is flipped over several times to create a faster composting process. After these four weeks the waste turns into compost outdoors under any climate circumstances. Mostly this process cost money and companies do not earn money because they give the compost away for free, like Attero itself.
3. Waste management

Still in some countries this composting process creates money and labour for poor inhabitants like in Bangladesh. (Schroeder, 2009) The composting process in Bangladesh is very easy because of their tropical climate and high percentage of organic waste in the trash stream.

Electronic waste

Electronic waste is different from the other types of waste cause it consist of hazardous components. This is why electronic waste is never completely recycled but more demolished for its valuable materials. Old electronics are being sorted on their type (computer, tv, radio etc.) and eventually tested if the devices still work properly. Eventually they are disassembled and the hazardous components are separated from the non-hazardous components.

Figure 18 shows that more or less 98% of the non-hazardous components can be reused. Which mean the plastic can be cut in small pieces and used for plastic recycling industry. Metals can be sold for the metal recycling industry. Though in fact this is not completely true. The plastics from electronic waste are mostly not being reused at all. In countries like China and India, the workers who search for valuable metals mostly burn the plastic immediately in order to get rid of the huge amounts of plastic. Or dispose the amount of waste to a landfill or incinerator. These burning and dumping processes create pollution and does not use the amount of plastic which can be recycled. (ECS, 2012)

Conclusion

To create a new product out of waste, specific treatments are necessary to create a final product with quality. Metals and glass need only a few treatments but those treatments are performed at high temperatures in order to reuse the material, while plastic can be recycled at a much lower temperature but with several treatments. Also the machinery needed to grind or cut metals and glass are more complex than plastics or paper. Basically the treatment processes of glass and metal are very complex and done at a high technical level. The treatment of textiles is done at a high technical level. With several special machineries, factories are able to reuse textiles on large scale. Paper needs a lot of chemical treatment processes to create fibres and remove all the inked.
3. Waste management

3.4 Effect and problems of waste
As explained before, waste is a definition for anything which is eliminated or discarded as no longer useful or required. This means waste itself is not useful anymore and developed into a burden.

In most cities, the municipal solid waste includes hazardous household waste (which means pesticides, coatings and paints, batteries, light bulbs and overdue medicines).

Cities in developed countries created systems which are designed to collect and handle these hazardous materials separately, or to prevent their generation and reduce their toxicity. Unfortunately even in developed countries only a few cities got a successful system to dispose these hazardous components. In most municipal solid waste streams include hazardous components when they reach disposal. (Tibajuka et. al., 2010)

Next to the hazardous waste, ‘normal’ waste disposal creates a lot of risks and problems. Composting and recycling also have an environmental impact for the health on the general population. Especially those who live near or work on a waste disposal site are exposed to the following threats. (Rushton 2010)

These threats create high health risks. Workers involved in waste management are constantly exposed to specific occupational risks and the injury rate is higher than in industrial work. Constantly exposed to specific occupational risks and the injury rate is higher than in industrial work. While standards and norms for handling municipal solid wastes in industrialized countries have reduced occupational and environmental impacts significantly, the risk levels are still very high in most developing countries because of poor financial resources and inadequate understanding of the magnitude of the problem.

Not only waste is a high risk for workers involved in waste management. Waste in general consist of many substances, such as arsenic, cadmium, chromium, dioxins, nickel and PAHs. These are considered to be carcinogenic and are able to produce toxic effect on the central nervous system, liver, kidneys, heart, lungs, skin, reproduction and other health effect.

Pollutants such as sulphur dioxide and particulates have effects on diseases and mortality. Chemicals such as dioxins and organ chlorines are lipophilic and accumulate in fat-rich tissues and have been associated with reproductive and endocrine-disrupting endpoints. (Rushton 2010)

3.5 Comparison solid waste management
Most data about solid waste is unreliable and seldom captures informal activities or system losses.

In the 1970’s developed countries started with modern municipal recycling because it is was less expensive as well as environmentally preferable then regional disposal. This meant a change in habitual behaviour of households, they had to separate their waste into several categories rather than mixing it all together. Also it needed a change for waste collection providers and operators, they have to change their way of working.

At the moment the developed countries are trying to deal with waste in a less pollutive and harmful way. But also NIC’s and developing countries are trying to change their waste management systems. Mostly public health crisis stimulates new initiatives to collect the waste and clean up the city. Though solid waste management is a major challenge for many cities in developing and newly industrialized countries. Cities create their own systems and ways of dealing with municipal waste. The collection system varies widely, ranging from 25 to 75 per cent in cities where the norm waste disposal is still open dumping. The problem of these open dumps is that it is stopping initiatives for creating a solid waste management system. These open dumps are cheap and authorities do not want to invest and offer competition for scarce financial resources to other critical municipal systems such as hospitals and schools. (Tibajuka 2010)

To give an overview about how all these different countries are dealing with solid waste management, a figure has been made with all the differences between least developed countries, developing countries, newly industrialized countries and developed countries. Of course there has to be kept in mind that each country and city got their own site-specific situations. Also not all the data of each country is reliable, Therefore this overview gives a rough comparison between the different type of countries.
3. Waste management

<table>
<thead>
<tr>
<th>Activity</th>
<th>Least developed countries</th>
<th>Developing countries</th>
<th>Newly industrialized countries</th>
<th>Developed countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MSW generation per capita</strong></td>
<td>0,80</td>
<td>1,71</td>
<td>1,18</td>
<td>2,19</td>
</tr>
<tr>
<td><strong>Total MSW generation (kg per day)</strong></td>
<td>905.719.511</td>
<td>1.386.394.990</td>
<td>4.467.671.640</td>
<td>1.748.395.160</td>
</tr>
<tr>
<td>Waste collection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Collection rate</strong></td>
<td>42,4</td>
<td>82,7</td>
<td>84,2</td>
<td>98,8</td>
</tr>
<tr>
<td><strong>Total MSW collected (kg per day)</strong></td>
<td>383.885.731</td>
<td>1.146.086.525</td>
<td>3.759.545.685</td>
<td>1.727.110.349</td>
</tr>
<tr>
<td>Disposal/Recovery</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open dumps (%)</td>
<td>20,9</td>
<td>22,7</td>
<td>21,3</td>
<td>0</td>
</tr>
<tr>
<td>Landfills (%)</td>
<td>59,3</td>
<td>54,2</td>
<td>59,7</td>
<td>36,5</td>
</tr>
<tr>
<td>Compost (%)</td>
<td>0,7</td>
<td>1,1</td>
<td>0,8</td>
<td>10,8</td>
</tr>
<tr>
<td>Recycled (%)</td>
<td>1</td>
<td>2,2</td>
<td>6,8</td>
<td>23,4</td>
</tr>
<tr>
<td>WTE (%)</td>
<td>0</td>
<td>0,6</td>
<td>1,8</td>
<td>18,4</td>
</tr>
<tr>
<td>Other (thermal treatment)</td>
<td>18,1</td>
<td>19,2</td>
<td>9,5</td>
<td>10,8</td>
</tr>
</tbody>
</table>

Developing countries recycle the most percentage of waste or try to use waste for generating electricity. In the other countries most waste is disposed in landfills. This means that they are not treating waste completely, and in those countries waste is a harmful threat for pollution in case the landfills are not save. This also means that in the entire world most of the waste ends in a disposal site and is not recycled or up-cycled into a new product. In order to create a global waste system, developing countries recycling processes should be integrated more in order to reduce the current waste. And developed countries should reduce the waste generation by social awareness.

3.6 Conclusion waste management

Solid waste management is a system to deal with waste. There are a lot of different ways to set up a solid waste management. High technology can be used but in some countries it is more feasible to use animal support. Money plays a key role in setting up a waste management systems. Also, there is never one system for all countries. Sometimes a more simple system can create more labour and therefore will increase the economics of a country. The western manner of solid waste management system cannot always work in a developing country. Not only because of their economical state but also because of their culture.

Another important conclusion is that all the steps in a solid waste management are always a polluting threat. No matter how well the system is arranged, emission and pollution for the environment will occur. Some SWM steps are of bigger concerns then others like open dumps.

Therefore in order to deal with solid waste, it is important to try to create a smaller waste stream by recycling, up-cycling or re-using as much as possible. Basically all types of materials can be recycled. Some with more feasibility then others but in theory it is possible. In order to create new products made out of solid waste, it is important to collect and separate the waste as precisely as possible.
The previous chapter explained the solid waste streams. It showed it is possible to recycle, up-cycle or even reuse products of any type of material. These products can be made as a high-technology product or a low-technology product. The differences between these is that a high-tech product is basically a product that uses, requires or is involved in a high technology. The product is made or developed in associated industrial use. A low-technology product is a product that uses or requires only low technology. This means that industrial technology is not being used. It is possible to make these products with simple tools without any industrial equipment.

4.1 State of the art

Products

In general there are a lot of waste products, for example: furniture, dishes, tiles, isolating material, bikes etc. The designs are endless and it is interesting how these ideas become reality with technology, techniques and materials. Still not all these designs are a success because of different factors. Sometimes the production process is too complex or too expensive. Furthermore it is possible the industry or society is not ready for a change or the product intents to be a solution but in reality the production process is pollutive and more waste is created.

There are some products which become a success because of their special production technology like the high-tech chairs from Dirk van der Kooij. During his graduation project at the Design Academy in Eindhoven, Dirk van der Kooij created ‘the endless process’ where he melts plastic into a paste and eventually different types of chair are printed from the paste with an old 3d printer. The techniques makes it possible to create any possible object. The used plastic, is the old pulverized case of a refrigerator and other e-waste. If the robot changes colours, the leftover plastic inside the machine is collected and re-purposed into coat hangers. His products now have a fashion statement and all his chairs are exclusive design chairs. (van der Kooij, 2011)

The strength and opportunities of this product is that waste is getting value in this design. Electronic waste is a massive problem in the world and by creating design chairs also the plastic becomes of great value. Another opportunity is that the technique is simple en different shapes can be created with the exact same printer. This makes the production process unique and it will be possible to adapt the system easily for other prospects.

A nice example for a low-technology chair is the chair of the design office ‘Onceneto’. They designed the ‘Conolounge chair’, a chair completely made out of cardboard tubes, leftover product from newspaper printers, which are attached to two steel supports. It is an easy process and can be done completely manual. (Onceneto, 2012)

The strength of this chair is the low-technical, low-cost and non pollutive production process. The weakness of the chair is its unknown lifetime, quality and the lack of a business-case of the product. The chair is not in production process because the office never aimed towards it. The chair is an item to create an image for its design office and there is no clear business plan for the future with this single design. (Onceneto, 2012)

There are also examples of buildings materials made out of waste. For example the company Affresol in England, designed the s- called Thermo Poly Rock. It is a low-cost material meant to use for social housing in England. The material consist out of plastic waste mixed with a resin. Together it forms a mouldable liquid which can be poured like concrete. It has the same strength as concrete as well. (Inhabitat, 2012)
4. **High-tech and Low-tech waste products**

Though at the moment the product is not very successful. People are scared to use the material because of its ‘waste’ image. Though it is a clean and strong product, the market is not ready for this new way of building social houses.

Another example of a waste building product is the Loofah panel high-tech. This is a building materials made from plastic PET bottles combined with loofah or corn husks combined with other materials.

There is a special machine made which can melt plastic and combine it with the organic waste into a mixture. The mixture is poored and pressed on top of a bamboo plate. This combination of materials creates a strong insulating panel.

This building materials also aims to increase the earning capacity of local women to start building these panels and selling them. In this way it is possible to create more independence and stable life for inhabitants. On very small scale the project has been applied in Paraguay. The project eventually failed because the price of PET bottles increased and therefore it was not anymore feasible to apply the loofah panels. The women could not any longer create an income with the loofah panels and therefore the project had to been stopped. (Meinhold, 2009)

4.2 Conclusion

This chapters show there are a lot of examples of waste based products. The designers themselves are convinced the product is sustainable and without any emissions. Still though these products fail because of a lack of interest by consumers, money-issues, politics or because the market is not ready the change. Sometimes the new production process is more pollutive then a non-renewable source while the intention is to create a cleaner product.

In order to compare different products in an analysis, it is important to compare them for the same criteria and target goal. Paragraph 6 shows the result of a multi criteria analysis. This analysis is applied in order to see how eight specific products could or could not work for slum areas. Beforehand it is important to define the needs and criteria for slum areas in paragraph 5. With those needs several criteria can be created to analyse the chosen eight building materials. **Appendix 2 & 3**
5. Housing Situation

UN-Habitat’s research provides the information that between 2010 and 2015 almost 200,000 people will be added to the entire world’s urban population each day. (UN Habitat, 2012) Governments in developing countries find it difficult to cope with this unprecedented urban growth. About 800 million people (about 25 per cent of urban population) live in slum settlements. This number of slum dwellers will increase to about 890 million 2020. (UN Habitat, 2012) Still each type of country got a different growing pattern and it is described below.

<table>
<thead>
<tr>
<th>Type of country</th>
<th>Urban population 2010</th>
<th>Slum population</th>
<th>Percentage slum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Least developed countries</td>
<td>173,108,103</td>
<td>124,054,315</td>
<td>71.66</td>
</tr>
<tr>
<td>Developing countries</td>
<td>472,652,844</td>
<td>174,710,388</td>
<td>36.96</td>
</tr>
<tr>
<td>Newly industrialized countries</td>
<td>1,598,358,602</td>
<td>446,680,406</td>
<td>27.95</td>
</tr>
<tr>
<td>Developed countries</td>
<td>728,931,893</td>
<td>26,643,420</td>
<td>3.66</td>
</tr>
<tr>
<td>Total</td>
<td>2,973,051,432</td>
<td>772,088,529</td>
<td>25.97</td>
</tr>
</tbody>
</table>

Figure 2: Slum population which are percentages of the urban population as a whole. Source data: United Nations, Department of Economic and Social Affairs, Population Division (2011)

This data shows that 70 percentage of the urban population of the least developed countries lives in a slum. At the moment 50 percent of the urban world population lives in a Newly industrialized country. These type of countries also got the highest amount of people living in slums. The population living in slums will continue growing because of the continuous movement from the population of agricultural areas towards urban cities. In order to cope with this growing ‘slum’ population, governments got to help the inhabitants with creating safe houses and living areas.

This paragraphs describes the current condition of slums and their houses. The different upgrading programs and their needs. (Greene et. al., 2012) (UN Habitat et. al., 2012)

5.1 Current use of houses in slums

The traditional meaning of slums are housing areas that used to be respectable but the original dwellers have moved to a new and better area of the city. The condition of these old houses have been deteriorated, and the units have been progressively subdivided and rented out to lower-income groups.

This means, a house in a slum is a different definition than a house in the western world. Houses in slums are any kind of low-income settlements and or poor human living conditions. Mostly the areas are densely populated, crowded, poverty and social disorganization. The materials used for the ‘buildings’ or ‘shelters’ are any kind of available material which differs from a brick to a plastic sheet. This is why the quality of dwellings in slums varies from the simplest kind of structure to permanent structures. While access to clean water, electricity, sanitation and other basic services and infrastructures are usually limited or in an unhealthy way.

(Hustwit 2011) (Tibaijuka et. al., 2003) (Bredenoord et. al., 2010)

In each area in the world there is a different use of slum. The quality of these slums are influenced by: culture, climate and economy. Slums can be divided into more or less two broad classes: ‘slums of hope or slums of despair’.

1. Slums of hope: ‘progressing’ settlements, which are characterized by new, normally self-built structures, usually illegal (eg squatters) that are in, or have recently been through, a process of development, consolidation and improvement;
   • ‘old’ city centre slums; and
   • ‘new’ slum estates

2. Slums of despair: ‘declining’ neighbourhoods, in which environmental conditions and domestic services are undergoing a process of degeneration.
   • Squatter settlements; and
   • Semi-legal subdivisions
5. Housing Situation

‘Old’ (inner) city slums
Inner-city slums are the first concept of slums. Like Tibajuka describes: ‘The process whereby central, prosperous residential areas of cities undergo deterioration as their original owners move out to newer, more salubrious and more fashionable residential areas’. (Tibajuka et. al., 2003) This process is very common and it is mostly an expected consequence of the growth and expansion of cities, discovered by both an increase in the central commercial and manufacturing areas and activities, and the flood of migrants for agriculture areas looking for employment in urban cities. (Bredenoord et. al., 2010)

The quality of inner city slums are structurally acceptable and provides ideal housing opportunities for those willing to cope with less space and shared facilities. Because the buildings were originally built for middle- and high- income groups, they are well serviced with urban infrastructure. This means the location and access of the buildings provides residents a good access to employment opportunities. Though, over time, the dwellings are increasingly subdivide and the when the level of overcrowding grows exponentially, the infrastructure will disappear slowly. (Tibajuka et. al., 2003)

‘New’ slum estates
New slums are public social houses or houses built by industry for their industrial workers. The new estates are built for renting and the ideas of these projects begins mostly very fruitful but because of lack of investment, appropriate dweller control or involved day-to-day management and maintenance the projects fails into a slum area.

These new slums are mostly located on the edges of cities, where land used to be available. Unfortunately access to work, markets and social amenities are not connected to these areas. Isolation is created because public transport is unaffordable to the low-income inhabitants. As a result the ‘public houses’ become abandoned, desperate and destitute. Eventually the creators of the projects abandoned the areas and the private residents, who face a lot of times unemployment, are unable to maintain the houses. Social problems occur because of the overcrowded population and pressured conditions. Mostly criminal organizations take over and there is political exploitation and corruption. (Tibajuka et. al., 2003) (Bredenoord et. al., 2010)

Squatter settlements (Consolidating informal settlement)
In rapidly developing cities, most of the urban development been through informal settlements. Land has been informally subdivided and sold or leased to households who have built their own dwellings. The land used in this way can be unsafe or unfit for planned residential development. In some instances, it is land reserved for future development that has been pressed into serving the needs of the otherwise homeless population. (Tibajuka et. al., 2003)

Over time, some of these settlements have been recognized, tolerated and even accepted, such as Policarpa Salavarrieta, a large 1960s land invasion in central Bogotá, Colombia. In the beginning there have been many attempts to destroy and remove these settlements. But by time there has been interventions to improve these settlements. Whether legal or not, their continued and permanent presence gives the inhabitants the right to exist and to develop their settlements.

Figure 29; Slum Beirut © Mohammed Asad
Figure 30; Dilapidating Chawl Façade, Mumbai, India ‘new’ slum estate © Nikhilesh Haval Nikreates
Figure 31; Squatter settlement Dharavi, Mumbai, India © Chandrashekar (Shekar) Manalam.
5. Housing Situation

These areas got a chaotic and organic overall appearance, because of the disorganized construction and improvement of those areas. There are less public facilities, such as schools, and a few formal commercial stores than in the established slums. With more owner occupiers and self-employed residents the general level of income is higher than in newer, poorer settlements.

The potential for improving these informal settlement is high as a result of the greater perceived and real benefits from upgrading for the residents. (Bredenoord et. al., 2010) (Tibaijuka et. al., 2003)

The planning and zoning legislation is in constraints to the government. Though in practice, the city government has learned to accommodate and adjust to the presence of these settlements. In order to maintain the land values and the areas that surround these consolidating slum settlements, it is important to absorb and improve these settlements within the formal housing stock. (Tibaijuka et. al., 2003)

Illegal settlements and subdivisions (Recent slums)
Recently developed slum neighbourhoods are often similar to the consolidated informal settlements, but are newer and unconsolidated. Their newness is expressed in poorer, less permanent materials, especially in settlements where residents are unsure of whether and for how long they will be allowed to stay before being evicted. In cities where evictions are common, or on sites where they are unlikely to be left alone, shacks are likely be very basic built of recycled or very impermanent materials (such as straightened oil drums, used corrugated metal sheets, plastic/canvas sheets, cardboard cartons and discarded timber).

Where authorities are more tolerant, or where such settlements are the norm for establishing new neighbourhoods (for example, around Lima), or if there are about to be elections, then the settlers are likely to build with more confidence, using more permanent materials and standards of construction. In either case, infrastructure is likely to be absent or only available through clandestine connections.

New or recently established slums tend to have lower densities as there are fewer constraints and less competition for the land; yet the individual plots and parcels occupied by each dwelling are unlikely to be any larger than in the more consolidated slums. This is because household tend to occupy only enough land for their individual needs, rather than explicitly seeking to profit from land holding and development.

Recently developed slums are generally found on the periphery of the built-up area of the city, or in pockets of even more marginal land than the more established slums. Increasingly, occupants of the newer slums often use the grid-iron layout, even without the assistance of external organization and support.

There are several advantages in adopting grid layouts:
- It is easy to lay out
- There is a stronger likelihood of obtaining urban services and recognition if the settlement is orderly
- There are likely to be fewer disruptions and demolitions when services are installed. (Tibaijuka et. al., 2003) (Bredenoord et. al., 2010)
5. Housing Situation

5.2 Technical state of slums

Overall the conditions of any type of slum are below humanitarian standards. These conditions differ per country, city, neighbourhood and even each house differs from each other in their quality. These differences are made with culture, economic state, available materials and the technical skills of inhabitants and type of slum. These type of slums differ in the quality of their materials, water supply, available electricity and their sewage system.

In order to define the technical quality of these buildings, the shearing layer model of Stewart Brand has been used. The shearing layer concept views buildings as a set of components that evolve in different time-scales. (Brand, 1994) The layers are:

- Site: this is the geographical setting, the urban location and the legally defined lot, whose boundaries and context outlast generations of ephemeral buildings.
- Structure: the foundation and load-bearing elements are perilous and expensive to change.
- Skin: Exterior surfaces
- Services: communications wiring, electrical wiring, plumbing, fire sprinkler systems, HVAC and moving parts like elevators.
- Space Plan: the interior layout. Like walls, ceilings, floors and doors.
- Stuff: furniture and other appliances. (Brand, 1994)

Each slum is analysed like the shearing layer concept, figure 36, in order to see whether or not some aspects of the building are missing and in order to see the possibilities. (Brand, 1994) To make it clear in the figures there are several colours used to explain the technical state for each type of slum. When a function got a grey colour, this means that the function is available in low condition or illegally available.

‘Old’ city centre slums

Old city centre slums are central residential areas which undergo deterioration. Their inhabitants move to newer residential areas. During the years the old central residential area develop itself into a slum because there is no investment any longer. This happen during the growth and urban expansion of big cities. Though, the location of these slums create a good access to work opportunities for slum inhabitants. Which makes those areas popular among slum inhabitants.

Also the quality of the buildings is acceptable. And inhabitants pay a low amount of rent because it is a legal building. This also means it consist of an old basic structure, mostly concrete, which is still of acceptable quality. The rooms inside the building are mostly later one added with alternative materials or the existing indoor walls are removed. This means an official space plan is missing.

There is a connection for services but because of a lack of maintenance the old drains and water supply pipes are leaking. Still these services can be considered as available or easy to reconnect and to improve the area. The skin of the building as a façade is available but in bad conditions. (Bredenoord et al., 2010) (Tibaijuka et al., 2003)
5. Housing Situation

This is why inhabitants try to improve their façade with alternative materials like steel sheets, plastic sheets and plywood. The location and the quality of the structure of the dwellings, gives it a good opportunity for improvement. Only the infrastructure, services and the skin should be improved in order to improve these dwellings and areas.

At the moment these areas are improved by completely renovating the buildings and make them attractive for middle-income or high-income levels. This means governments, remove the inhabitants without providing them a new shelter. This creates issues and does not solve the housing problems in cities. (Tibaijuka et. al., 2003)

Slum estates
Slum estates are houses built as public housing estates or houses built by industry for industrial workers. There is a lot of criminality and political exploitation. Therefore the houses end up as forgotten areas. Which means cities do not help to maintain the houses or involve with the economical state of the inhabitants.

The houses itself consist of a basic structure with a façade. Services like water supply, sewage system and electricity is available but because inhabitants are not always able to pay for these services they vanish in the years. In general these slum estates consist of all the basic needs. Unfortunately after some years the services are disappearing because of a lack of maintenance, lack of investment and because nobody is paying the bills for these services.

The façade and roofing are damaged during the years and inhabitants try to fix it themselves with alternative materials. In order to improve these dwellings, mostly the skin and the services should be repaired and social services should be added in these areas. (Tibaijuka et. al., 2003)

Squatter settlements
Squatter houses are houses built by squatters, so called people who occupy land or buildings without the explicit permission of the owner. The areas grow together into one big slum area. The entire area consist of settlements built illegal on governmental ground. Those slum areas cannot be removed without offering a new area for inhabitants. Therefore, inhabitants are not afraid to built their settlement, and therefore the entire area defers in quality. Some inhabitants invest more in their homes than others.

The structure and skin are mostly made of durable materials which create a chaotic (organic) overall appearance. This means any type of available cheap material is used like: steel sheets, plywood, plastic sheets, wooden elements etc. The services are unofficial available which means that people try to connect themselves in an illegal way to water pipes, sewage and the electricity net. This creates an unsafe water supply and sewage system which creates diseases and pollution. In order to improve these dwellings, mainly the outside skin should be replaced and if necessary the structure should be repaired. Services like water supply and a sewage system need to be added in a legal and safe matter. (Tibaijuka et. al., 2003) (Bredenoord et. al., 2010)
Illegal settlements and subdivisions
Semi-legal subdivisions are illegally built slum areas outside city services. Because these settlements are illegal and next to dangerous living conditions, like rivers, dump-sites etc., the inhabitants are aware of the possibility that their houses can be removed. This is why the entire settlement is built with impermanent materials like oil drum, corrugated metal sheets, plastic and canvas sheets, cardboard cartons and discarded timber.

These settlement do not have any kind of services available. The shower and toilet are shared with neighbours as an unofficial sewage system close to rivers. Basically everything should be improved to upgrade these dwellings. The services are missing, there is no strong structure available and also the façade consist of an inadequate condition. (Tibajuka et al., 2003) (Bredenoord et al., 2010)

Conclusion
All these slum types have different appearances with each other and within the different slum types. Sometimes inhabitants have skills to improve their house themselves, while others do not have the skills to improve their house with simple material. Therefore it is difficult to describe a single need for all the houses. In order to create a product, two types of slums are chosen to upgrade, the squatter settlements and the illegal settlements. Both of these slum areas do not consist of a solid structure but are built with an unofficial wooden structure. The other type of slums consist of a concrete or brick structure, which can be optimized by closing the façade with heavy materials like roof-tiles and bricks. This improvement will create a strong appearance and will last for several years. While a wooden unofficial structure will not last long and is therefore suitable for a product which can be applied and replaced after a few years. Also, these type of slum areas are in very dangerous conditions and an improvement for their house is not enough. Therefore a product should be considered as a temporary affordable improvement until they can afford a proper home in a safe area.

The inhabitants of these houses found a way to create a structure, or use an existing structure. But they need a material to make a waterproof house and protect them from criminality, climate etc. They use corrugated steel panels, sheeting membranes, bricks and any other available material. All this material helps them to improve their house, but is not suitable for the use. For example, plastic sheeting material, is very fragile and needs to be replaced often. Corrugated steel panels are strong, watertight (because of their overlapping structure) and easy to assemble. Though it does not insulate well and it gives thermal expansion and movements, rapid corrosion, and heavy noise with rain. Bricks, on the contrary, are strong and suitable for a house. But not every inhabitant can afford bricks, or is not sure to stay long in their current house. Therefore the investment in brick material is too expensive.

Basically a material is needed which can be used for their façade and roof systems and improves the quality of the current alternative used material. A panel would be suitable, to apply it on their existing structures and to make it possible to create a roof and façade out of the same material.
5. Housing Situation

5.3 Upgrading programs
In order to create a healthier and more aesthetically living situation in slum areas, governments and organizations like UN habitat are trying to upgrade slums in different countries. Providing material, financial programs, education, creating an income for local inhabitants etc. Not all these improvements work because of a lack of finance facilities and non-governmental support. Or because of non corresponding upgrades. For example if a settlement is improved, this does not immediately mean that the life of an inhabitant is improved as well. If there is not a stable income, the house will vanish after a few years because of a lack of maintenance. In order to create a successful program, improvement of a settlement is not enough. The entire social and economical environment of a slum needs to be improved. (Bredenoord et. al., 2010) (Golubchikov et. al., 2004) (Hannula et. al., 2012)

5.4 Conclusion
As explained before, the technical, social and economical environment of a slum need to be improved. All these needs are ordered and translated into regulations for a new product.

Technical
Inner city slums, slum estates, squatter settlements and semi-legal subdivisions have one need in common. They need an outside material which can be applied against their current existing structure. Currently, their structure is closed with alternative materials like cardboard, plastic sheets, corrugated steel panels etc. Cardboard is not waterproof and plastic sheets are very thin which creates bad insulating properties. Corrugated sheets are easy to overlap on each other on existing structures, showing bad insulation properties, noise and thermal. Therefore a new waste based product should bring an improvement to the current corrugated steel panel. Also inhabitants will not own special machineries and therefore this product should be applied with simple tools.

Economical
Slum areas are areas for urban poor population. There is no money available and the material/product should be as cheap as possible. The maintenance, production process and the final price should be as low as possible.

Environment
Any new kind of slum product should not be pollutive or toxic for human beings. It should be a safe product without any emissions in order to create a safe and healthy environment.

Social
Social aspects such as high criminality rate and no stable income, play an important role for slum areas. In order to apply a new product, inhabitants should be involved within the production process. By generating not only an improvement for their house but also a stable income. Another social aspect is the visual improvement. At the moment all the slums look chaotic and undefined. In order to not only upgrade the buildings socially but also create an aesthetic appearance, inhabitants will appreciate their housing more and try to maintain it themselves.

Requirements
Basically the requirements of the product for a slum will be:

Economical
• Low price product (made with available materials)
• Low-cost production process (low-technical process)
• Low maintenance costs

Environmental
• Non pollutive emissions

Social
• Create an income
• Production process around the area

Technical
• Waterproof material
• Overlapping structure (waterproof connections)
• Sound insulating
• Thermal improvements
• Lightweight, less then 25 kg (people able to carry)
• Measurements (able to be carried by one person, door measurements)
• Simple tools needed: handsaw/hammer/screwdriver/nails/screws
6. Waste products for slum areas

To compare different products/materials with each other, out of the list of appendix 15 eight products are selected. A multi criteria analysis, MCA, is applied in order to check what kind of material and production process is the most suitable of all for slum areas. The materials are selected based on the type of waste material the production process. From each type of material, one low-technical product and one high-technical product is chosen to compare with each other. Appendix 3 shows a detailed description of the MCA analysis.

6.1 Multi criteria analysis

A multi-criteria analysis, MCA, is comparing measurable sets of criteria to assess how different options are achieving intended objectives. A MCA is an assessment method that tries to supply an unrefined view on the many different dimensions on the options. Key elements of the MCA method are the performance matrix, the weighing and the ranking process. The performance matrix gives an overview on the scoring of all evaluated options with respect to all criteria taken into account. (Kirkels, 2012)

Normally it is difficult to make judgments on different alternatives taking into account more than seven criteria at once. But a MCA can easily supply more than seven criteria. Therefore a MCA has its methodological problems that should be tested for their robustness in the sense of a sensitivity analysis. Hereby the robustness of the weighing factors are checked. An actor analysis checks how the ending scores will change when the products are analysed in the view of different scenarios. (Kirkels, 2012)

Top goal MCA

In this MCA the goal of the study is to provide an insight in order to check what kind of products is the most suitable of all for the needs of slum areas. The top goal is stated as follows: which out of the different products made out of waste is the most suitable for slum areas in emerging countries in terms of availability, low-cost, high-tech quality and improvement of current situation.

Alternatives MCA

There are many different building products made out of waste made. The products are produces in a high-tech or low-tech way. In order to make a good comparison between all the options from each waste components only plastic, paper, organic waste and combined waste are chosen. From each waste components, two products are chosen and will be compared. All these products and their specific production processes are described in appendix 2.

Plastic
1. Pollibrick
2. Plastic bottle houses

Paper
3. Paperbrick Spain
4. Paperbrick India

Organic waste
5. Stak blocks by Oryzatech
6. Hempcrete

Combined waste
7. Loofah panel high-tech
8. Loofah panel low-tech

The MCA is divided into four sections, objectives. Each objective contains a number of criteria described below.

Economics

Economics is a crucial factor in order to make a product a success on a market. A product for people without any money, means that the economic factors even influence more the success of a product than a product where the end user is able to pay an amount of money.

- Production local market
- Price
- Costs
6. Waste products for slum areas

Environment
The reason for waste as a building product is to decrease the amount of waste in the world for housing purposes. Environmental effects of this product are crucial in order to check whether or not this product meets its requirements, or if it creates more waste and pollution in the environment.

• Future use
• Emissions

Social criteria
The main goal is to create a building product for slum areas. This means it is a social goal which should meet some criteria.

• Health
• Social improvement

Technology
The construction of the building product has to meet some technical criteria in order to be able to be used as a building product.

• Lifespan
• Reliability
• Practical to handle

Appendix .. describes the objective and their scores precisely in order to understand the meaning of each score for each type of product.

6.2 Results
A sensitivity and actor analysis are applied to check whether or not the applied weighing factors and criteria are reliable. appendix 3.2.1 & 3.2.2. With these analysis a final conclusion about the results can be described as following: loofah low-technical design comes out as the best option. This is understandable because its designed from a social and economical view but it reaches the technical standards. The product is produced in a low-technical manner with cheap non-pollutive materials to create an income and better housing situation for poor inhabitants. It reaches the technical standards by applying organic waste which creates a high insulation value and with a natural tuna coating it is completely waterproof.

All the products which are involved with plastic waste, come out as the least desirable option. This is mainly because of its pollutive high-technology production process or the future use is not defined.

Furthermore, all the low-technology production processes have a better score than the high-tech production processes of the same materials. For example, loofah low-technology design scores better than Loofah high-technology design and low-technology paper-brick India scores better than high-technology brick-Spain. This is mainly because the low-technology design got a cleaner production process and because the technical quality which the high-tech production processes are not always achieved. Furthermore on small scale like a house, the quality of a material got different needs than on bigger scale like an apartment building. The structural strength can be much lower and therefore complex production processes are for some materials not necessary.

6.3 Conclusion
This MCA shows a low-technology product fits better with the demands of slum areas. A low-technology production process can create work opportunities, house improvement and therefore a future for slum areas. In order to create a low-technology product, a strategy is needed to develop this product. The next chapter explains all the followed steps towards the development of the new product and its material.
7. Product Development

Once the needs for slums areas are identified a product can be developed. This product must be waste based, and therefore the developing of the material is a crucial step of the process. The chart shows an overview of the steps involved in the development of the product and its material.

Low-tech process

**Building element**
- façade/roof cover
- structural element
- floor element

**Type product**
- panel
- brick
- membrane tent

**Type Binder**
- formaldehyde
- bio-based binder
- plastic waste

**Type of Plastic**
- mix
- others
- PE
- PET
- PP
- PS

**Type of Waste**
- glass
- metal
- organic
- paper
- textiles

**Process**

**Treatment**
- without preparation treatment
- preparation treatment: drying waste

**Process**
- cold pressure
- hot pressure
- baking process
- extrusion

**Temperature**
- melting temperature
- glass temperature
- define temperature

**Pressure**
- 0 kN
- 20 kN
- 100 kN
- 200 kN

**Time**
- 5 min.
- 10 min.
- 15 min.
- define time

**Ratio (binder/waste)**
- 40-60%
- 50-50%
- 60-40%
- 80-20%
- 90-10%
7. Product Development

7.1 Building element
As mentioned before, slum areas need a product which covers the façade and roof areas from their already existing dwelling structure. This ‘structure’ consist mostly of light materials like wood. At the moment they try to close this structure with alternative materials like cardboard, plastic sheets, corrugated steel panel etc. For example, these corrugated sheets are easy to overlap on each other on existing structures, showing bad insulation properties, noise and thermal. Therefore a new waste based product should bring an improvement to the current corrugated steel panel.

7.2 Type of product
After reviewing three covering options, it has been decided that a panel can be applied for multifunctional purposes. For example a brick can only be applied for the façade, but not for a roof. Therefore not all inhabitants can use the product, while it is important to give the product several functions. A membrane element, like a sheet, can be applied for as well roofing as façade but this material is hard to produce with waste. Waste material got hard elements and to create a soft tin material can be complex to produce with low technique. A panel on the contrary, is a hard board with different elements. Somehow the material should be kept together with a binder but all type of material can be mixed within the panel. Therefore a panel is a potential type of product.

This panel will be used as a cover material for slum houses, therefore it is important the material and product succeed on several requirements which need to be tested to check if the material and product are succesful. These requirements are set up according the ‘ontwerpproceduremodel’. This model creates a difference between primary and secondary requirements. The primary requirements are the requirements for the closure of the structure, cover material, the secondary requirements are all the other requirements. Therefore, secondary requirements are not of less importance. (Lichtenberg, 2002)

<table>
<thead>
<tr>
<th>Material</th>
<th>Primary requirements</th>
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<tbody>
<tr>
<td></td>
<td>• Waterproof</td>
</tr>
<tr>
<td></td>
<td>• Strong (should handle maximum windforces)</td>
</tr>
<tr>
<td></td>
<td>• Fire resistance</td>
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<tr>
<td></td>
<td>• Thermal resistance</td>
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<tr>
<td>Secondary requirements</td>
<td></td>
</tr>
<tr>
<td>Emissions</td>
<td>• No emissions during use</td>
</tr>
<tr>
<td></td>
<td>• No emissions during fire</td>
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<tr>
<td></td>
<td>• No emissions during physical contact with the material</td>
</tr>
<tr>
<td>Use</td>
<td>• Possible for nail and screw connections</td>
</tr>
<tr>
<td></td>
<td>• Prevent biological corrosion and degradation</td>
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<tr>
<td></td>
<td>• Prevent thermal conduction</td>
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<td></td>
<td>• Safe to be in conta</td>
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<table>
<thead>
<tr>
<th>Product</th>
<th>Primary requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Waterproof connections</td>
</tr>
<tr>
<td></td>
<td>• Strong (should handle maximum windforces)</td>
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<td></td>
<td>• Fire resistance</td>
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<td>• Optional thermal insulation properties</td>
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<td></td>
<td>• Sound insulation</td>
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<td>Secondary requirements</td>
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<td>Emissions</td>
<td>• No emissions during use</td>
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<td>• No emissions during fire</td>
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<td>• No emissions during physical contact with the product</td>
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<tr>
<td>Use</td>
<td>• Fire resistance connections</td>
</tr>
<tr>
<td></td>
<td>• Possible for nail and screw connections</td>
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<tr>
<td></td>
<td>• Possibilities for replacement and reparability</td>
</tr>
<tr>
<td></td>
<td>• Lightweigh, less then 25 kg</td>
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<tr>
<td></td>
<td>• Thermal resistance connections</td>
</tr>
<tr>
<td></td>
<td>• Prevent nesting pest and vermin</td>
</tr>
</tbody>
</table>
7. Product Development

7.3 Type of binder

There are different type of panels in the market like: metal panels, wood panels, polymer panels, cement based panels and gypsum boards. All these panels have their own specific properties, use and production process. In order to create a production process for waste based panels, it is important to have knowledge about the current panel production processes.

An analysis has been made, to create an overview of production processes from all types of panels. And to give insight into the effect of type of binders and several production techniques on the panels. This analysis is shown in appendix 4. Metal boards are not included in this analysis because metal consumes to much energy and effort to recycle, up-cycle or even cut it. Paragraph 3 & appendix 5.

The analysis reveals the strength of the panel is highly depended on the binder, as shown in figure 43 and 44. A formaldehyde resin creates a good tensile strength, while a phenolic resin is more suitable for the compressive strength. It is possible to improve or change the properties by adding additives or fibres used in the correct direction, like with the cement boards.

It is clear, for each binder there is a different production process. Formaldehyde based panels are produced with hot compression techniques, gypsum boards are all produced with a plasterboard technique and cement boards are cold compressed.

The production process can be optimized to create an optimum panel. But the binder decides the pressing method, temperature and its ratio.

An overview of the properties, benefits and applications of different binders are provided in appendix 4.4 to support the decision of the final binder. It is important for a binder to be waterproof, UV-resistant and non toxic for people so the panels can be cut and adapted in their size. Most binders are considered as toxic, especially epoxy, polyimide and formaldehyde are very toxic binders.

Therefore these binders are less suitable because of the release of emissions. Formaldehyde based binders should be avoided because of this extreme toxic properties unless the production process avoids people to get in contact with the liquid formaldehyde binder. (Golubchikov et al., 2004)

Several researchers have been trying to replace the formaldehyde binder by a bio-based oil binder. At the moment these binders are still under development, there is not much information about its properties. Therefore this binder will not be used as an option.

Another option is the Acrodur binder from BASF, formaldehyde free, which consist of the same properties as phenolic formaldehyde. A negative element of this binder is release of water during a production process. Vapour will be released during the warm compression, this means the compression takes longer and involves pauses. At the moment this binder is not available in all markets, only Europe and parts of Latin America. (BASF, 2009)

All these options will increase the cost of production. In order to create a feasible product, it is desirable the binder is a type of waste itself. Plastic can be melted and mixed with other materials. After cooling down this product, the plastic will go back to a solid phase and the other waste is bound within the plastic.
7. Product Development

7.4 Type of waste

In order to choose a waste material to mix with plastic, it is important to gather information about which materials in the world are being collected, separated and recycled. Unfortunately this is not an easy task. In general, every type of material can be collected, manually or electronically, separated and eventually recycled into a new material. As explained by Hoornweg & Bhada-Tata, the recycling rates compositions depends on global markets, shipping costs and prices. It is a market which varies a lot and mostly metals and glass are recycled. Plastic is recycled but not everywhere on large scale. Because the amount of plastic is so high, it is hard to recycle it in the same rate as it is produced.

![Figure 45: Total MSW disposed Worldwide © Hoornweg & Bhada-tata](image)

The MSW disposed rate worldwide shows, the most amount of waste is still dumped in controlled landfills. This creates difficulties because not one material can be point out as the least valuable one of waste. In order to create a product which can help slum areas it is important to build an economic market behind it. Valuable materials such as metals and glass are already commercialised by the recycling market worldwide, while other like paper, organic waste and all types of plastic are possible to use.

**Paper**

As explained before in chapter 3, the paper recycling industry separated all the paper into different grades of quality.

1. Corrugated cardboard (all type of cardboard boxes, panels etc.)
2. Mixed paper (phone books, paper-board, magazines, catalogues)
3. Old newspapers
4. High grade de-inked paper (this type of paper consist of a high gradation of ink on the top of the printer)
5. Pulp substitutes (clean pulp waste from paper industry)

For example high grade of de-inked paper needs a lot of detergents to clean the paper and create a clean pulp for the recycling industry. This type of paper is less suitable to recycle. Also mixed paper needs more investment to create clean pulp with high quality. Basically these type of paper is not suitable for recycling in the paper industry and would be suitable to use in different purposes.

**Organic waste**

Organic waste is in most countries dumped in open landfills or converted into compost. During the visit to Attero, appendix 7, it was seen the compost process is easy as long as the organic waste is separately collected from other waste. All the organic waste is checked for metals and bricks. After this check-up, the waste is chopped into pieces of 10-15 cm. The organic waste is stored for four weeks in a building under moisture control. The moisture influences the compost process and after these four weeks the waste turns into compost outdoors under any climate circumstances. This process costs money and companies do not earn money because they give the compost away for free, like Attero themselves. In some countries this composting process creates money and labour for inhabitants like in Bangladesh. *(Schroeder, 2009)* Where the tropical conditions accelerates the biological decomposition. Inhabitants collect their own organic waste, which after a while they sell as compost. Because of this small scale collection, a high percentage of organic waste is not used. Normally this waste is dumped or burned, and got no value at all.
7. Product Development

7.5 Type of plastic waste binder
There are a lot of different types of plastics, some categories are made in order to recognise recyclable plastics. During the MCA analysis, appendix 3, it is seen a lot of products made out of plastic can be toxic during the production. Therefore it is necessary to check which type of plastic is suitable. Appendix 8 shows the properties of plastics. As an example, PVC consist of styrene which is constantly leaking out of the material. When PVC burns it hydrogen chloride gas and dioxin, making them not suitable for housing purposes. While the leaking of expanded polystyrene is still under debate. (designerdata, 2013)

Therefore four types of plastics are chosen for further investigation, based on their low toxicity. PE, PP, PS and PET plastics are safe to use and therefore interesting to apply for building purposes. In order to check their suitability some material tests are done, appendix 9. The testings show only PET, PP and PS are suitable to use. PE plastic is too weak and absorbs a high percentage of water, 8%. Every type of recycled plastic can only handle certain percentage of pollution, another type of plastic. When combining different types of plastic from a waste source, it is difficult to control the exact amounts of each plastic in pure matters. Therefore a mixture of plastics is not suitable, appendix 7&9.

7.6 Process
Since plastic is used as the binder, a suitable production process needs to be created to promote binding between organic waste and plastic. During the melting process of plastic, organic material will stick to it. After cooling it down to 20°C, the combined material forms a solid phase. So the basic steps of the production process involve, mixing (plastic and organic waste), heating up and pressing.

To determine the optimum temperature, pressure and time it is important keep all these factors in control. Therefore a fontijne press is used in the Polymer laboratory of Mechnical engineering at the Technical University of Eindhoven. This pressing machine consist of heat pressing elements. They can cool down or heat up a mould with temperatures between 0-600°C.

Temperature & Time
To determine the pressing temperature, solid plastic boards are made without any additives. Hereby there can be checked at what temperature it is possible to create a plastic solid board. No pressure is applied, only heat to check at what temperature the material starts binding together without the influence of other factors.

Because the melting point of PS plastic is 240 degrees. At the test the initial temperature is set at 180°C, and gradually rised till it is fully melted. PS panels can be melted within a temperature range of 200-230°C. This temperature range is influenced by time. With temperatures of 200-215°C, the panel needs to be heated up for at least 10 minutes. While with higher temperatures, the panel is fully melted with a time of 5 minutes.

The melting point of PP plastic is around 170 °C and its softening point is between 100-165 °C. During experimental work, it was found that PP plastic does not melt at a temperature of 160 °C. Therefore the initial temperature is set at 180 °C, and gradually reduced until it solidifies. At a temperature of 170 °C for 5 minutes, the panel is not fully melted. Therefore the time is increased to 10 minutes.
7. Product Development

Even after those 10 minutes, the panel breaks and it is obvious the PP plastic not fully melted with each other. Therefore the melting point for this recycled plastic is around 180 °C for 5 to 10 minutes.

This means, recycled PP does not correspond with the theoretical melting temperature for pure PP plastic. This is influenced by additives in the material like colourants, glue types, pollution etc. Based on these findings, it is advised to check the melting point of the raw material before starting the production process.

Pressure
In order to apply pressure, different scenarios are created. First the consistency of binder/waste is defined at a constant pressure of 100 kN. If a panel succeed, the pressure will be reduced to 20 kN and the goal is to eventually to create a panel with a pressure of 0 kN. If a panel does succeed without any pressure, this means that with limited pressure the panel can be further improved. At a higher pressure, the temperature can be much lower. Therefore for panels with PS plastic, the temperature is reduced to 180 °C.

Ratio
In order to find out an optimal ratio of the material, several scenarios are created. The first attempts are made with dried wood shavings in stead of waste. In the end it turned out, wood shavings are not comparable with organic waste. Therefore two more experiments have been performed, dried waste and untreated waste.
Dried waste creates solid fully melted panels. The optimal ratio consist of 50 percent of dried waste with 50% of PP or PS plastics. Figure 50 and 51 show the outcome of the panel.

Untreated waste contains moisture and therefore the panel is not able to bind. Due to the high water content, the growth of bacteria’s or fungi is stimulated.

7.7 Material tests & properties
In order to determine if the material has the required properties to be used as a building product, the following primary and secondary requirements must be tested: water absorption, insulation value and structural strength.

7.7.1. Structural check-up
In order to check if the material is suitable to use as a façade and roof material for slum areas. It is important to check the structural strength of the PP-waste panel and the PS- waste panel.

Before a 3-point-Flexural test has been applied, while a 4 point flexural test gives more precise information then a 3 point flexural test. Though plastic shows elastic behaviour and therefore a 4 point flexural test cannot be applied and the 3 point flexural test is needed. In order to compare the current outcome with the original test it is important again a 3 point Flexural Test will be applied.

Appendix 5. This check-up will show if the material gets weaker or stronger with waste material as a filling.
Figure 53 and 54 show the test set-up. A force is applied in the middle of the panel surface. This force is raised with a constant speed of 2,1 mm/min. The deflection is measured with a deflection meter, figure 54. The pressing machine is connected with a computer in order to create a graph of the pressure and deflection.

3 point flexural test - graphs/calculations
To make a comparison of each group all the graphs per panel are combined into one scheme. (figure 105 appendix 11) The maximum force for PS waste panel is around 200 Newton and for PP waste panel 501 Newton. Calculations are made to calculate the maximum wind force on a small house and the maximum q-force on each type of panel. (Appendix 9 & 11)

The maximum wind force on a small building surface gives a q-force of 0,79 N/mm² and the maximum wind force on a roof of a small building gives a q-force of 1,26 N/mm². Therefore the panels should be able to maintain a force of 1,26 N/mm². The PS waste panel consist of a q-force of 1,6 N/mm². And the PP waste panel consist of a q-force of 4,0 N/mm². Both of the waste panels are able to maintain the maximum force and therefore are suitable as a cover material for an existing structure.

An existing structure is needed because at the moment the calculated wind force are extremely low because slum areas are mostly applied in dense cities. Though sometimes a slum area can be applied in a more open area of a city or storms can occur. In order to handle these more heavy forces it is important an existing structure supports the panels.

7.7.2. Heat transfer analyser
Appendix 11 shows the results of the heat transfer analyser. The average thermal conductivity for the PP waste panel is about 0,128 W/mK. And for PS waste panel is about 0,11 W/mK. This shows the insulating value for the material is similar as for wood materials, 0,04 - 0,21 W/m.

7.7.3. Water absorption test
The water absorption test show both of the material absorb a minimum percentage of water. This percentage can be reduced by making sure the surface of the panels are made with a thin layer of pure plastic. Beforehand the mixture of waste and plastic is applied to the mould, a thin layer of pure plastic needs to be applied.

7.7.4. Experimental discoveries
During experimental work some aspects are discovered. The main discovery is that it is possible to create a product/panel made out of waste without any additives. With one type of plastic it is possible to create a binding between dried waste. The ratio will be fifty percent dried waste and fifty percent plastic waste. The other discovered aspects are about the shape possibilities with the used production and its practical aspects.
7. Product Development

It is possible to create flat elements, but as soon as a ruthe in the material is created (like a corrugated shape) it is extremely difficult to remove the material from the mould. During the production phase a test panel of 5x2x0.5 cm has been created in corrugated shape. It was not possible to remove this small element from the mould and the entire panel broke. Even with silicon layers sprayed on the mould and baking paper applied, the material would get stuck because of its corrugated shape. Another problem which occurs with a corrugated shape, is that the plastic and dried waste will not equally be distributed. Gravity makes sure the heavy elements move towards the lower elements and in the end the panel cannot be strong. The only possibility of creating the corrugated shape is by forming the solid panel after the production in a form-station. The panel can be heated up and formed into any possible shape.

During experimental work, there was an experiments with two mould on top of each other. This was applied to check if it is possible to create more thickness with two moulds. Though it is not possible, the plastic get stuck between the two moulds and the moulds need to be separated with heavy equipment. In order to create more thickness, a completely new mould should be made. With a low-technical production, not many equipment will be used and therefore difficult shapes will create a more complex production. In order to make the material succeed, it is important to keep the material simple in order to create a smooth and successful production process. Therefore it is possible to create shapes into one surface of the panel. The rest of the panel can be kept as a flat element. The cover of the mould will create a pattern in the upper surface. Hereby it is still easy to remove the panel from the mould and the ratio of plastic and waste is well distributed because the panel itself is still flat. With a gradation in the surface, connections can be optimized and this will create more possibilities to apply the panels.

Another discovery is that it is possible to cut the material into a different measurement with a simple saw. No special or heavy machinery is needed.

7.8 Conclusion

In order to create a product for slum area purposes, several steps are followed. First of all the needed building element and the type of product with its requirements is described. The product will be a panel which will close open wooden structures. This panel will be made with a plastic waste binder consisting of PET, PP or PS plastic. The plastic will bind dried organic and paper waste by a hot pressure process. The temperature of this pressure process depends on the melting point of the chosen plastic. During the tests, no pressure is applied to find out the perfect melting temperature, melting time and waste-binder-ratio.

After experimental work the waste/plastic-ratio is defined at fifty percent dried waste and fifty percent plastic waste. The pressing time depends on the seize of the panel. For a small panel, 160x100x4mm, five minutes is needed to heat up the mixture. A bigger and thicker panel will therefore need more heating time or an applied pressure to reduce the total heating time.

Several tests are applied to check the properties of the panel. The panel succeed on its structural strength, water absorption tests and its insulation value. This means, it is possible to create a suitable panel out of waste without any additives.

The panel is created in an experimental environment with controlled laboratory machinery. In order to use this type panel for slum areas, it is important the production process is further developed into a more practical process. Chapter eight shows this process with all the needed production steps and machinery.
8. Production process

As mentioned earlier, material composition and binder types define the production process to follow, for the manufacturing of panels with the desired quality. The production process is meant to be done manually with use of basic tools, furthermore small machinery is conceptually designed. Every step is explained to create a clear description for future creators of the product.

8.1 Safety regulations
Currently the recycling & sorting centres in developing countries fail because the site itself is not well designed or safety or worker get infections because they are not provided with safety regulations. Therefore all the processes should be executed following local safety and health regulations. In addition, safety and on the job training shall be provided for all workers. (HSE, 2013) (Hennepin county, 2014) (HSE, 2014)

8.2 Production process
Figure 54 show the production process of the new material.

1. Gathering process
   **Collection**
   The waste collection differs per country. The sorting process becomes easier if the waste is separately collected, but this rarely happens in least developed countries. If waste is not separated this will provide more labour work is needed for sorting. Mostly there is a reason for the current collection stream, like money and labour issues. Therefore the collection stream should not be changed for the production process, but the production process needs to be adapted to the current collection stream of the area.

2. Sorting process
   **Separation**
   The waste is brought to the collection centre and waste pickers will be sorting the recyclables out of the waste. The waste will be sorted on big scale first. So the waste pickers will be separating: metals, glass, plastics, paper & organic material. The organic waste is brought to the preparation area. The metals and glass can be sold or brought to the metal and glass industry. The plastic will be brought to a secondary sorting centre.
8. Production process

There all the plastic is separated into its plastic recycling code, appendix 1.5. PET, PP and PS plastic is removed and used for the final product. The other plastics are sold or brought to the original waste treatment plant. Like explained in chapter 3, the paper recycling industry separated all the paper into different grades of quality. The paper with the least quality will be used for the panel production and all the other grades can be sold to the paper industry.

3. Preparation

Plastic

It is important to have a high quality sorting system to get the plastic material as pure as possible, less then eight percent of pollution. (Meeting Benny Luijsterburg, appendix 7)

Cleaning

Plastic is collected along with all types of waste, cleaning is needed. This can be done by adding soda and water to the plastic. Some plastic types float so it is important to stir, to insure all the plastic is rinsed by the soda water solution. The plastic is removed, dried and ground.

 Grinding

All the plastic waste is ground into pieces of about 3-8 mm. To effectively transfer heat and promote the melting. The grinding process is done with a small plastic grinder. After the grinding process, the plastic is ready to be melted.

![Image of a plastic shredder/grinder](https://via.placeholder.com/150)

**Figure 58: Example of a plastic shredder/grinder © Jordan reduction solutions**

Organic & paper waste

The preparation of this organic and paper waste is very simple, drying and grinding. It needs to be dried to remove all the water, to make sure the water does not influence the binding properties with plastic. During testing is was found, wet waste is difficult to grind into pieces. It blocks the knives and eventually the grinder stops grinding the waste.

Drying process

The drying process is a time consuming step of the production process. The waste needs to be dried for 2-6 hours in a temperature above 75 degrees. At lower temperature, the drying time increases. In warm countries the waste can easily be dried under the sun, lowering the energy consumption of the process. While at a cold or in high humid conditions, a different process needs to be applied. The waste can always be dried in an oven, as done during experimental work. It is also possible to create a natural drying area within a building, an attic can be created where hot air will flow and the waste can be dried in these places. This will take more effort to design and also the drying time will be longer, and the waste will be releasing odours. Therefore for health reason, the natural drying process by the sun or an electric oven is more suitable.

Grinding/shredding

The waste will be ground in a grinder similar to the plastic grinder in small pieces of about 5 - 10 mm. This is an easy process because the waste will be dried and easy to cut.
8. Production process

4. Moulding process

The final phase is the moulding of the panel itself.

Weighing

In order to create a proper panel it is important to have the exact ratio of plastic and organic waste. During the experimental work, a 50 ratio was found as a suitable ratio to create a strong solid panel. The panel standard size will be about 1200x900x10 mm. This standard size is chosen to create a panel which can be carried by two persons in its mould. The mould itself is made of steel and therefore heavy. If the panel is within this mould, it is still possible to carry the element with two persons. (Average weight mould, 1400x1100x10mm, of 36 kg, panel weight of 10 kg. In total a weight of more or less 46 kg, which is still less than 25 kg per person).

Each plastic has a different density, which influence the amount of kg of plastic to be added per panel. All the possible combination are described in appendix 12.1

Mixing

The mixing process is another important element of the production. The waste and plastic are mixed in order to equally be distributed within the panel. This mixture is applied in a mould.

Pressing

Time

During the pressing phase, time, pressure and temperature are kept constant. For an element of 1200x900x10 mm, the heating time is fifteen minutes. Experimental work showed the small samples of 5 mm thickness require between 5 and 7.5 minutes. Samples with a thickness of 10 mm require 10 to 15 minutes. Therefore the optimum time will be set to 15 minutes for bigger panels if heat is applied on two surfaces. If only heat is applied on only one surface the time needs to be increased to at least 20 minutes.

Temperature

The melting temperature varies with the type of plastic. Experimentally the temperature has been determined. PS needs a temperature of 200-230 degrees and PP of 180 degrees while the melting temperature for PET could not be determined. This melting temperature should be compatible with the maximum temperature of 250 degrees corresponding with the flammable temperature of organic waste.

Pressure

During experimental work, no pressure was needed to create solid panels. It was found any increase in pressure will improve the surface quality. Therefore applying pressure is advised by means of a manual screw, based on the old fashion laminating wood industry. Figure 57 gives an overview of the basic design of the machinery needed to produce such a panels.

In order to heat up the mixture, several options can be applied. For example the heating elements can consist of tubular immersion heating elements which can be placed between steel sheets to conduct heat to the surfaces, known as hot plate. With a simple button the temperature can be arranged and the elements can be switched off easily. The amount of watt a heater uses with a maximum length of 1200mm is 1200 watt. The heater can be applied in different voltage and ampere areas. Every country got its own specific voltage and ampere maximum. For example, the Netherlands got a 240 voltage net, with a maximum of 16 ampere per fuse, which creates 3840 Watt per fuse. Therefore two immersion heaters can be applied for one fuse. (Watco, 2014) This equipment is easy and safe to use, though electricity is necessary while slum areas are not always connected to a electricity net.

Another option could be a hot oil heat transfer system. These systems pump hot oil through pipes, which can apply the heat to a steel plate attached with the mould. The oil is heated up in a fire and a pump circulates the hot oil. Though in order to control the temperature the system gets more
8. Production process

Organic waste is flammable at temperatures above 250°C. Therefore it must be sure the temperature of the hot oil does not rises above this temperature. Industry uses hot oil to create temperatures above 250°C and temperature lower are created with hot steam. Hot steam needs a lot of progress to be created which is not feasible for small production.

Therefore the system of a hot oil heat transfer system is used in a very basic manner. Thermal oil, a homogeneous product, is poured into a steel surface, similar to a closed mould, an open fire with gas is applied under this steel surface. Without pressure it is possible for the oil to reach temperatures up to 300°C. The gas fire is applied because it is possible to control the flow of gas to the fire and arrange the temperature. The fire heats up the oil and a temperature meter is applied in the oil to check if the temperature is kept constant. There will be heat losses because an open fire is used. But because thermal oil is a homogeneous product, the oil will expand the same amount of temperature to all the surfaces. A hand pump is applied to pump the hot oil from beneath the mould towards on top the mould. By gravity, the cold oil will go back down to the bottom mould which can be heated up again. In order to make it possible to remove the top hot plate, a one-way hose connector is applied which can be opened and closed. Therefore the hoses can be removed without leaking oil out of the plates.

The steel surface of the oil box will transfer the temperature to the mould which heats up the mixture. Because the hot oil is transferred by a hand pump there will be thermal loses. It is also important some pressure is applied with the screws on top of the machine, to make sure the panel will not bend into a different shape because of possible temperature differences within the material. After 15 minutes, the mould is removed and could down at a natural temperature. During this cooling time, heavy elements like bricks are applied on top of the mould to make sure the panel will stay as flat as possible. Meanwhile a second mould can applied on top of the oil steel surface. This will create a larger scale manufacturing process.

8.3 Conclusion

The production process creates labour for slum areas, accountable for the drying and cutting process of organic and paper waste. The plastic will be treated by sorting, cleaning and grinding processes. A small simple low-technology press is designed, which makes it possible to heat up the mixture and apply pressure with simple screws. The machine is based on old wood laminating machinery combined with a basic oil heating application. After the production process, the panel is ready to be used as a product. The product itself is further described in the next chapter.
9. Final product

Before the product is explained there are some factors that need to be discussed. The quality of the existing housing structures in the slums can be defined as enough. Therefore the product will be attached to the structure as a cover material. The product will be produced with the production process described in paragraph 8. Two types of moulds are used to create panels. The strokes made with one mould will make the connection between the standard panels. An additional feature of the product, is that an optional insulation layer can be applied. A double layer of panels will be applied with a layer of dried waste in between. This insulation layer can be applied after a few years or immediately. This will depend on the slum state, whether it is a legal area or an area which can be removed by governmental parties.

9.1 Elements
The elements are made with two different moulds. One mould for standard panel, and one for the connection strokes.

These strokes are meant to keep the panels attached with each other and to create a connection point to the structure. If this element is not applied, there is a bigger risk of leakage and non stable connection. The strokes have a groove on one surface which is inspired by modern roof tiles. If water enters the connection, the groove will lead the water away from the roof. The groove is created with the cover of one surface of the mould.

9.2 Connection elements

Wall connection
The principles of creating horizontal and vertical connections are similar. The stroke is connecting two elements with each other in horizontal and vertical direction. On top of the strips the panels are attached. The upper panel overlaps the panel below, so-called bevelsiding. This overlap is created to make sure water does not enter the building.

Roof connection
For roof applications, a grid structure is needed to support the roof panels. Therefore with strips a grid is created to apply the panels on top of each other. The grid is applied with small groove within the strokes. The groove removes water and creates waterproof connection. This grid makes it possible to attach the panels on the roof against the existing structure.

Insulating layer
The additional feature of the product, is an optional insulation layer. A double layer of panels can be applied with a layer of dried waste in between. This insulation layer can be applied after a few years, or immediately. These layers are connected by strips and follows the same overlap, bevelsiding, as the original wall. This will make sure, water does not enter the façade.

Nail connections
Simple nails are used to connect the panels. Currently, bottle caps are used with nails to prevent leakage from the opening the nail creates in the corrugated steel material. On the contrary, the new waste panel material closes around the nail opening because the plastic shows a sealing property. This means the material does not scratch open around the nail but creates a cover around the opening.
9. Final Product

Figure 61; Panel types

Figure 62; Mould standard panel

Figure 63; Mould connection strokes with groove on a surface

Figure 64; Vertical connection

Figure 65; Horizontal connection panels with structure

Figure 66; Vertical connection double layer insulated wall

Figure 67; Roof connection side view

Figure 68; Nail connected through two panels front view

Figure 69; Nail connected through two panels side view

1. Standard panel
1200 300 300 300

2. Three Connection strokes

9. Final product
9. Final product

9.3 Assembling

Wall
In order to assemble the panels on an existing wooden structure. It is important to follow certain steps, in order to create a logical assembling system.

1. First of all the lower back-structure, made out of the panel strokes, needs to be attached to the existing structure.

2. The panels can be attached to these strokes with nails. If necessary, some panels can be cut into small sizes.

3. After this phase, the higher back-structure made out of panel strokes can be attached.

4. Eventually all the other panels can be applied against the strips. All the other walls can be repeated with this system until the entire façade is closed.

Roof
The roofing follows more or less the same principle as the wall assembly.

1. First of all the grid, made out of the panel strokes needs to be attached to the original structure. It is important the grid is overlapping with each other. With this overlap it is possible for water to follow the grooves from the strokes in the grid.

2. One by one, the panels are connected to this grid.

3. If all the panels are connected, the roof is finished. There need to be checked if any openings on the side of the roof needs to be closed.

9.4 Insulating assembling
The additional feature of the product, an insulation layer can be applied from the outside part of the wall.

Double layered wall
1. The vertical and horizontal connecting strips are applied on one panel of the low part of the wall.

2. The panel is connected on top of these elements and the open space between the two panels can be filled up with dried waste. This dried waste will create an insulating buffer between the two panel walls.

3. The vertical strip is connected to close the entire space between the two panels.

4. This system is repeated until the entire lower wall consist of an insulating buffer.

5. The same system is used for the upper wall to fill the wall with dried waste and to apply the panels.
9. Final Product

**Wall assemble**

- Figure 70: Lower back structure is applied
- Figure 71: Panels below are attached and upper back structure is applied.
- Figure 72: Finished wall.

**Insulating wall assemble**

- Figure 75: Strips applied on existing wall
- Figure 76: Panel connected on strips, filled with dried waste and about to be closed on the side.
- Figure 78: The wall is filled with dried waste and closed on the upper part by a strip.

**Roof assemble**

- Figure 73: Grid is attached to original structure
- Figure 74: Panels are connected to the grid.

**Figure 71; Figure 73; Figure 74; Figure 76; Figure 77; Figure 78;**
9. Final product

9.5 Product analysis

**Weight**
The panels have a size of 1200x900x10 mm. The weight of the panels is 10 kg. This weight makes it able for people to carry the panels without any problems alone, and with two people to carry the elements in the mould. Because of the small size, it is easy to carry the panels and apply them to a house.

**Sound insulating/reduction**
The single layer is only sound insulating with its own material and therefore very limited. Though because the connection is made with stripped elements, there are no openings between panels. This will reduce the noise nuisance. The current used corrugated steel sheets are applied on the roof. Because of the steel material, the material increases the noise created with rain and other climate influences. The new panel is made out of waste in combination with plastic. The plastic itself will mute the sound from climate influences in stead of increasing it.

The double layered panel got even more sound reduction properties. In order to reduce the sound transmissions through an element, mass can be added to the system. Buchanan, defines that a double layered sandwich panel will reduce the sound transmission losses, figure 74. Though this will cost more investment for inhabitants. Also it will create extra production steps and the meaning will mostly not be understand. Therefore another system is used to apply mass between the panels. Between two panels, a layer of dried pieces of waste is applied. This layer will create a buffer zone and consist of closed connection elements, which will prevent sound loses through openings.

**Thermal insulating**
The thermal insulating elements are created by the material. The insulating properties for the PP waste panels are about 0,128 W/mK and for PS waste panels about 0,11 W/mK. This means a single layer of panel will create an insulation value of more or less 0,09 m²K/W. A double layered panel with the dried waste will have an insulation value around 0,43 m²K/W (two times a plastic waste wall and an dried waste area compared to the properties of cork). These insulation values are limited but an improvement of the current corrugated steel sheets with an insulation value of more or less 4,16 • 10⁻⁴m²K/W.

Also the currently used corrugated steel panels transfer heat and cold easily into the building because of its bad thermal properties. This new plastic panel on the contrary does not transfer heat or cold that easily into the building because it consist of plastic instead of a metal material. Therefore the new panel does improve the current circumstance but need to be developed further to create an more comfortable material.

**Fire resistance**
The material itself consist of plastic and organic and paper waste. Organic and paper waste is flammable and plastic waste will melt and drip during fire or high temperature circumstances. This dripping can create severe skin burns. This means the material itself cannot be fire proof. A fire-resistant coating is needed to be applied on the panels. These coatings are available in different type of colours such as: white, black or transparant.

![Figure 79: Double panel and their transmission loss in decibels © Buchanan, 2007](image-url)
9. Final product

A white fire-resistant coating can be used, to also improve the reflection properties of the roof panels. The white colour will reflect the sun to prevent heat entering into the house.

In order to create fire-resistant connections of the product, it is important to close gaps between materials. Smoke and fire can go through a product by finding gaps. Therefore overlaps are created which prevents these circumstances.

MCA analyzes
Paragraph 6 shows an MCA analysis which provided information about suitable products for slum areas. Appendix 3 This MCA analysis has been applied again to check if the ‘new’ panel comes out as the best option for slum areas out of all the other product and is therefore successful as a product. Appendix 13

The result of the new MCA, is that the new panel is the best option together with the loofah low-technology panel. Both of them are produced in a local market with low prices and costs. There is a strategy for future use and the waste created during its production phase is kept low. Both products have a strategy for technical housing, social and economical improvement for the slum areas. At the moment the new panel achieves a lower score than the low-technology panel on the lifespan and emissions. For the new panel, both of these factors are uncertain and therefore the panel should be developed into a more precisely defined product in order to become more successful.

9.6 Conclusion
Theoretically the product could work for a slum area. But in practise unknown problem can occur. Though there are already some failure points of the material and product which need to be developed and improved.

First of all, the lifespan of the material is unknown as well as the climate consequences. The sun can damage plastics and therefore it is possible the plastic top layer of the panel will be destroyed. Which means the organic waste is exposed and can start a biodegradation process which will destroy the entire product. There need to be checked in what kind of time range this damage will occur. If this degradation process occurs after five years, it is easy to replace a panel for a new one. Though if this process occurs after two months, the entire product needs to be adapted because the replacement needs to be done in a very short time.
Also the fire resistance of the product needs to be tested and further developed. At the moment there is assumed a fireproof coating will work to slow down the burning process during fire. Though not only the fire itself but also the released emissions during fire are of extreme danger for inhabitants. Therefore the product needs to be tested and improved on its retardants in order to be qualified as a ‘safe’ product during fire circumstances.

In order to be qualified as a safe product, all the emissions during the lifespan of the product need to be tested. Plastics emit toxics during its lifespan. Most of the emissions are unsure because it depends not only on the type of plastic but also on its use and exposure. The plastics used for the product are labelled as ‘safe’ type of plastic, but are mostly used for the packaging and food industry. The exposure in slum areas will be different and can have a different effect on the plastic.

Slum areas itself are also a critical point for the product because these areas are more polluted then other urban areas. Therefore the panels need to be applied in an area similar to slum areas in order to check the effect and exposure on the material and the product.

Also the assembling method needs to be optimized for the insulation walls. At the moment strips are applied for one panel, the panel is filled with dried waste and closed on one side. This process is repeated for every type of panel and therefore this assembling method takes time and asks for focus of the assembler. This entire system needs to be created more simple and understandable in order to succeed.

Another critical point of the product is its production process. A theoretical machinery is developed but has never been built or tested. Therefore the machinery needs to be developed, tested and further developed in order to check if the production process will be reasonable and practical for these typical areas.
10. Conclusion and Recommendations

10.1 Conclusion

The main goal of this research is to effectively make use of the available waste and improve the houses in poor urban areas, so-called slums. The goal within the research is to explore a solution by developing a product made out of waste which satisfies current needs for slum areas.

In each country, there is an existing waste stream, where valuable materials are sold. An opportunity has been found to valorise available waste material such as plastic, paper and organics into a new product. It is important to keep the current waste stream actors involved with this production.

Currently, slum inhabitants are able to create a structure for their houses, where corrugated steel sheets/panels are used to cover the façades and roof surfaces. These corrugated sheets are easy to overlap on each other on existing structures, showing bad insulation properties, noise and thermal. Therefore a new waste based product should bring an improvement to the current corrugated steel panel.

Social aspects such as high criminality rate and no stable income, play an important role in slum areas. In order to apply a new product, inhabitants should be involved in the production process. By generating not only an improvement for their house, but also an income.

Therefore a low-technology production process is more suitable for slum areas. This way inhabitants can be involved with the production and with simple tools and low investment it is possible to set up the production. While a high-technology process, needs more investment and the product will be too expensive to apply for slum areas. Metals and glass need heavy equipment and high temperatures to be recycled into a new material. Plastic, paper and organic waste can be treated with less complexity, making them suitable for a low-technology up-cycling process. The plastic material shows binding properties and is used to keep the other mixing materials together.

Experiments for this research showed it is possible to melt plastic at low temperature, between 180 - 230 degrees, and mixing it with organic waste and paper. After cooling down, the plastic will go back to a solid phase and the organic waste and paper is bound within the plastic. The best outcome is a ratio of fifty percent of dried waste in combination with fifty percent pure PET, PP or PS plastics.

A small simple low-technology press is designed, which heats up the mixture and applies pressure with simple screws. Controlled heat is supplied with an open gas fire, which heats up thermal oil. This thermal oil exchanges the heat to the mould. After twenty minutes, the mould is removed and naturally cooled. Meanwhile the cooling is applied, a second mould can be melted. This will create a large scale manufacturing process of the same type of panels.

The final product is made with two types of moulds. One mould create the standard panels and the other mould created the connection strokes. The strokes will make the horizontal, vertical and roof connections between the standard panels. An additional feature of the product, is that an optional insulation layer can be applied. A double layer of panels will be applied with a layer of dried waste in between. This insulation layer can be applied after a few years, or immediately.

The production process creates labour for slum areas, accountable for the drying and cutting process of organic waste. The plastic will be treated by sorting, cleaning and grinding processes. After the production process, the panel can be used. Therefore this product fulfils the current needs for slum areas with its use and production process.
10. Conclusion and Recommendations

10.2 Recommendations
This report shows it is possible to create a waste product. But in order to start producing the product, several elements need to be investigated or tested.

Production panels

Prize recycling industry
The recycling industry is in development for different types of materials. Metals is a valuable product for the recycling industry with a more or less stable prize worldwide. Though the prize of plastic differs within years, months, days and areas. If the value of plastic increases, a more feasible recycling process can be applied. Though the costs of the new waste panel will increase as well. Inhabitants will not be able to buy and use the product for their homes, and it is possible to product will fail. In order to prevent the failure of the product because of the competing recycling industry it is important to do more research in the specific applied area. Information about their recycling industry is needed to adapt the production process towards this industry.

Waste stream
Each country has its own specific waste stream which is based on opportunities for labour, economical advantages, techniques etc. The waste stream will influence the quality of the final panel and therefore the production process need to be adapted to this waste stream. Therefore it is important a research is done beforehand the panel production is applied in an area to find out how the currently used waste stream is applied.

Production machines
The conceptual machine need to be made, tested and improved. It is important the temperature can be controlled, and it needs to be easy to remove and apply a mould in the machine.

During production there are lot of thermal losses. The pressing machine is heated up below and a hand pump is pumping the oil through the two plates. More research needs to be done to controll these heat loses and to improve this machinery. Therefore the entire machine needs to be produced, tested and optimized.

Use of panels

Material tested in a slum
It is important the final product is tested and optimized within a slum. At the moment the lifespan of the material is unknown as well as the climate influences. Slum areas are very pollutive areas. It is possible the material get damaged with influences that are not yet considered because of their unusual existence. Therefore this material should be applied in a slum to check in what kind of way the material should be improved.

In order to be qualified as a safe product, it is also important all the emissions of the material during the lifespan and fire circumstances are measured and recognized. The exposure of emissions to people can be of extreme danger and at the moment the emissions are not measured.

Use of product in slum
Not only the material itself, but also the product needs to be applied in a slum area. There need to be checked if slum inhabitants are able to apply the product for their house. There might occur unknown problems specific for an area. Currently, slum inhabitants are forced to built their houses themselves, therefore they have specific knowledge about their own homes. It is possible they want to apply the material for a different purpose or in a different manner. This needs to be checked and improved.
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