A survey of recycled plastic waste as an alternative building material

-a field study of low-income housing in Bogotá, Colombia

Abstract
This study charts the possibilities of recycled plastic and its use as an alternative building material for low-income housing in Colombia. The building materials in the study have been compared with respect to their physical properties and how they affect the indoor climate in buildings constructed with plastic bricks and clay bricks.

Background
An eager to make a positive impact on the planet emerged into finding an area of use for all the plastic waste not taken care of properly. We quickly narrowed it down to the locations of the planet where people are affected the most, that is developing countries without proper waste management. A correlation between the lack of proper waste management and poverty as well as housing shortage gave birth to the idea of recycled plastic as an alternative building material.
We have decided to compare the two building materials regarding the following factors:

- Structural strength
- Thermal conductivity
- Heat capacity
- Thermal expansion
- Construction cost for new housing
- Indoor climate

Problems
Our planet is drowning in plastic pollution and the capacity to handle plastic waste is already overwhelmed. Only 9% of the nine billion tonnes of plastic the world has ever produced has been recycled. Most ends up in landfills, dumps or in the environment (UNEP 2018). . China is the largest producer of plastics, followed by Europe and NAFTA. A global production of 348 million tonnes a year (Plastics Europe, 2018), the same weight as 696 pieces of the world's tallest skyscraper, Burj Khalifa (The World Federation of Great Towers, n.d). This contamination causes alterations in the soil by not degrading and becomes a dangerous nourishment for wildlife to consume. In addition, 99 % of all plastics are produced from fossil fuels, which are limited and non-renewable (Sierra Jiménez 2016). Further problems that are current is the following:

- Substandard housing
- Inequality gap
- Poverty

Increased recycling and education in construction will empower vulnerable communities so that they can assemble their own houses in order to become pollution free and safe. This will help mitigating global warming and help decrease the extreme poverty gap. The method of self-help housing has a high social, environmental and economic impact and is endorsed by UN's Sustainable Development Goals, especially the 11th goal, Sustainable Cities and Communities (UNDP, n.d.).

Method
Through this study a feasible construction material for use in housing has been examined. The material is made of recycled plastics (HDPE), for instance from plastic bottles, jugs, plastic lids and textiles. A comparison has been made between a house constructed by recycled plastics and a house constructed of masonry, which is the most common building technique in Colombia.


Figure 2. Test of thermal conductivity.


Figure 1. Test of compression strength.

Masonry
The main structural construction materials are reinforced concrete and masonry in Bogotá. Masonry is common in seismic regions of Latin America, and in Colombia it has been used since 1930's. Masonry in low-cost housing can be divided into two main groups:

- Non-engineered masonry
- Engineered masonry

Where the latter can be further divided into the two most popular groups:

- Reinforced masonry
- Confined masonry

Confined masonry consists of an unreinforced masonry wall confined with a reinforced horizontal and vertical concrete frame. However, when building houses in low-income areas this building technique is often performed in the wrong way. The vital methods and criteria are not being used in the right way which results in a poorly strengthened houses.


Figure 4. Column ready for casting.


Figure 3. Inadequate masonry houses in Usme.

Brickarp & Conceptos Plasticos
The housing system that is studied is based on a construction material that creates no pollution or negative environmental impact since it's made of recycled plastics and does not require more extraction of raw material. These bricks contain recycled thermoplastics (HDPE/HDPP) that have the following benefits:

- High melting point
- Excellent chemical resistance
- Lightweight, inexpensive
- Modular
- Does not require skilled labour to be assembled
- Disassembled since it's not constructed with mortar or similar


Figure 5. Plastic house of 56 sqm without frame supplements.

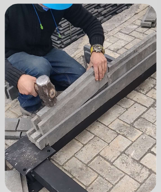
Figure 6. Method of mounting plastic bricks.

Thermal comfort
The indoor climate is important for health, well-being and productive work. A dwelling with poor indoor climate enhances the risk of health problems such as:

- Headaches
- Abnormal fatigue
- Irritation of the skin and mucous membranes (eyes, upper respiratory)

In combination with the previous symptoms various types of stress and individual circumstances like allergies or other hypersensitivity issues, the problems may be exacerbated.

However, the concept of indoor climate is broad and highly subjective, thus difficult to evaluate. It is also an individual estimation since humans prefer various climates due to:

- Clothing
- Activity
- Age
- Gender

The thermal environment can be related to thermal comfort which is often defined as the range of climatic conditions within which the majority of persons would not feel thermal discomfort, either of heat or of cold. In order to determine if the thermal comfort is comfortable, we use ANSI/ASHRAE Standard 55-2010, which is an adaptive model where the comfort zone is defined with reference to indoor temperature and the average temperature of the outdoors during a month. This method is applicable when determining an acceptable thermal environment for occupant-controlled naturally conditioned spaces that meets the following criteria:

- No mechanical cooling system (e.g., refrigerating air conditioning, radiant cooling, or desiccant cooling) installed.
- No heating system in use.

ANSI/ASHRAE Standard 55-2010 shows the allowable indoor operative temperature.


Figure 7. Installing Tiny Tag in masonry house.

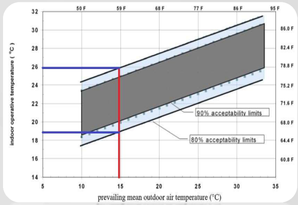

Figure 8. ASHRAE, acceptable indoor temperature.

Studied houses
The study consists of two houses, where the design and the occupants' activities are equal, and they are located in an area with similar climate. The houses are located in different areas of Bogota due to the lack of plastic houses that can be studied. However, the areas where the houses are located has similar climate and altitude, the houses are approximately the same size, 40-50 sqm, and are both suitable for low-income families with simple designs. The homeowner of the plastic house chooses to be anonymous.


Figure 9. Masonry house of the study, located in Usme.


Figure 10. Gap between plastic bricks, due to expansion.

Indoor climate
The value of average outdoor temperature in May was calculated to 14.8 °C which gives an average indoor temperature between 19 °C and 26 °C to achieve a comfortable indoor climate according to ASHRAE (see Fig. 8). These values will be used as reference lines in Fig. 11 & 12 to demonstrate when the indoor climate transcends the acceptability limits.

Results
The plastic housing meets the comfort requirements considerably better than the brick house. Beyond this, one can still see that the indoor climate is not within the comfort requirements throughout the whole day. The difference in temperature indoors and outdoors is approximately the same, 5 °C, during all 24 hours of the day. Therefore, the nights are well below the comfort zone while the days meets the requirements.

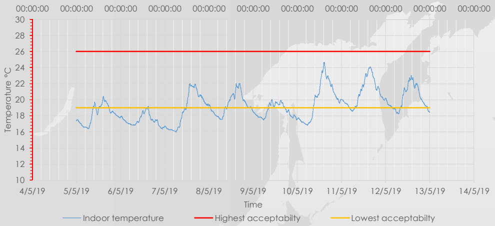

Figure 11. Measurements from masonry house.

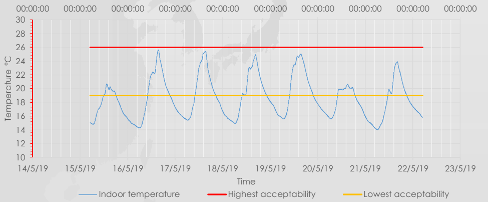

Figure 12. Measurements from plastic house.

The thermal expansion coefficient and the probability of cracks appearing between bricks when exposed to diagonal pressure is considered as the biggest issue of the construction, due to the gap it creates between bricks. First and foremost, the movement of the bricks limits its area of use.

As for properties in strength, the plastic material is equal to clay bricks and masonry in many aspects and deviant in some. The biggest distinction is the structure and how it behaves when failing. Clay bricks is a strong material but breaks instantly while the plastic material stretches and fails slowly. Due to this fact, it could be used in seismic areas to prevent sudden collapses of bearing structures and therefore prevent fatalities caused by falling objects.

The cost analysis shows that the plastic house is approximately 24% less expensive to construct.

Type of test	Clay bricks		Plastic brick
	Vega Vargas 2015	Lopéz Restrepo 2013	Sierra Jimenez 2016
Compression strength single brick [MPa]	9.8	5	5.7
Compression strength mortar [MPa]	21.5	11	
Tension strength [MPa]			5.7
Compression strength prism [MPa]	5.3	1.48	6.08
Lateral compression strength full-scale wall [kN]	1.3	4.11	0.435
Thermal conductivity λ-value [W/(m*K)]	0.6		0.42
Heat capacity [J/(kg*K)]	1000		1270
Volumetric heat capacity 10^6 [J/(m³K)]	1.0		1.4
Dry density [kg/m³]	1700		1100
Thermal expansion coefficient 10^{-6} [1/K]	4-6		130

Table 1. Collection of data from material properties.

Further investigations
During the investigations of the material a pungent smell from the plastic bricks was noticeable. An emission test would therefore be necessary to determine that there are no toxic substances that could harm the residents.

Byggteknik med arkitektur - 2019

Finansierad av Sida & Campus Vänner

Eric Svenmyr & Olof Wadsö