Sustainability criteria for urban planning

Quantifying potential reductions in environmental impacts of building systems in the Aburrá Valley, Colombia.

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*ABSTRACT: Accelerated and uncontrolled growth of cities is causing social problems, damages to the territory, the environment and its ecosystem. Because of this, it is required a new model city that minimizes consumption while reuses resources and reduces the need for new raw materials. In this context, a country like Colombia has implemented new standards for sustainable construction and major cities of the country has developed Public Policies in these issues. In order to have a greater impact, urban planning strategies with sustainability criteria are demanded. This paper aims to determine the potential to reduce environmental impacts associated with the materials, between an industrialized building system and a conventional one, applied on a large scale urban intervention. Study case is an urban regeneration process in Sevilla neighborhood, located in the city of Medellin, Colombia. According to the results, the industrialized system generates **41.2% less CO_2 emissions and 52% less waste** from construction waste than a traditional system. Applied in the partial plan of Seville, this equates to a reduction in **65.446 t CO_2 emissions and 81.029 t less waste.***
Keywords: Regenerative design, eco-efficiency, Sustainability, Carbon footprint.

INTRODUCTION

Metropolises of developing countries, located in Asia, Africa, the Middle East and Latin America, are growing rapidly and are facing high levels of inequality, economic inequity and of extreme poverty, with deficits in access to housing with utilities, control of waste, health services and security. Accelerated population of cities, also causes social problems, damages to the territory, the environment and its ecosystem.

As cities grow, they tend to increase their demand for energy, water and raw materials, which leads to high consumption of resources and dependence on surrounding areas, which supply the urban conglomerate. Similarly, under a model of linear metabolism, these cities pollute on a large scale, producing greenhouse gas emissions, discharges and solid waste without any management. That's why, it has increased the need for a model city, under a closed cycle, a circular metabolism that minimizes consumption while reuses resources and reduces the need for new raw materials. (Rogers & Philip 2015)

In this context, a country like Colombia, in the process of economic growth, located in the tropics, with large sources of natural resources that have not been properly managed, in the midst of an energy crisis, and given the urgent need to build a model city sustainable, suggests new rules of sustainable construction. The purpose of this national Standard, is to improve the quality of people's lives and promote actions with environmental and social responsibility, through the construction, according to the global interest in reducing environmental impacts. At the same time, the two main cities, Bogota and Medellin, have set up Public Policies for Sustainable Construction, in order to establish guidelines and criteria that contribute to the sustainability of the regions, at the level of planning, design, construction and operation of the built environment (AMVA & UPB 2015).

At the level of urban management, it should be noted the relevance of these strategies, since, according to Anuario Estadístico de América Latina y El Caribe (Statistical Yearbook for Latin America and the Caribbean) in Colombia about 81,5% of the country's population lives in cities in 2015, a figure that is growing every year (ONU-CEPAL 2011). The metropolitan regions must respond to their own growth, but also to the population migration from the countryside, because of the lack of opportunities in rural areas and the conditions of violence. This condition is a challenge for urban planning of cities, in terms of urban densification and the implications on the environment, the rapid increase of real estate development.

The Metropolitan Area of the Aburrá Valley, is a conurbation made up of 10 municipalities, including the city of Medellin, the second largest city in Colombia. It has approximately 3.8 million inhabitants, concentrated in urban area of 170 km^2, located in a narrow valley, almost completely built, where few areas of urban expansion remain (Area Metropolitana Del Valle De Aburra 2007).

The situation of the Aburrá Valley, in terms of housing and infrastructure deficit, has also obliged to generate land use plans, which allow densification in height, the redevelopment of already consolidated and renewed urban areas, accompanying these plans of urban, environmental and social standards. (Alcaldia De Medellín 2014). The compact model densified city, implies social opportunities, as well as greater social and ecological advantages, since integrated planning can increase energy efficiency, consume fewer resources, produce less pollution and control its expansion (Rogers & Philip 2015).

Thus, amid growing cities, the construction of both new buildings as existing interventions, leads to an increase in demand for building materials. In the metropolitan area of the Aburrá Valley, 77% of the buildings are constructed in confined masonry, 14.9% used an industrialized building system, primarily walls cast in concrete or prefabricated, and 6.4% are developed with structural masonry (AMVA & UPB 2015).

Although the construction sector, is one of the largest industries in the region, many of its implementation processes can still be considered crafts, far from being classified as industrialized, as they generate large waste materials, because labors are performed by unskilled workforce.

While the selected construction system, can have a significant effect on the sustainability of a building, adjusting the impact at urban level, allows large-scale dimension, the environmental burden of tons of waste from inefficient systems and executions, which are built with the Colombian cities today.

Given this context, and considering the growth strategy for the city, and also Public Policy for Sustainable Construction for the Aburrá Valley, including a guide on urban planning (AMVA & UPB 2015), this paper aims to determine the potential to reduce environmental impacts associated with the materials, between an industrialized building system and a traditional one, applied on a large scale urban intervention

METHODOLOGY AND DEVELOPMENT

To develop this research, quantitative methodologies were adopted, which enable the analysis of the environmental impact indicators, produced by the manufacture of building materials and the construction process of urban renewal plan, taken as a case study.

Two construction systems were taken as reference, conventional masonry, which respond to the strategies of the city model and current management; and an industrialized system, more efficient and less polluting. The research was made in two parts that allowed determining the reduction potential impacts mentioned: 1) Quantification of systems emissions and their application to the study case; 2) Quantification of waste from demolition and construction in the study case.

To perform the quantification of emissions, it was considered, as a tool, the calculation of the carbon footprint, which allows the impact measurement of a product on the planet, in terms of emissions of carbon dioxide (CO_2), which are released to the atmosphere due to industrial processes, necessary for manufacturing. This analysis covers all activities of the life cycle of a product, from extraction of raw materials to their disposal as waste.

Air emissions have to be analyzed from two points of view: the polluting emissions with direct impact on local air quality, generated specifically in the construction phase; and emissions of greenhouse gases GHG, that occur throughout the project life cycle and its materials, contributing in that way, to the phenomenon of global climate change.

Considering the above, they are taken as reference, emission factors of polluting gases into the atmosphere, in relation to the physical and chemical processes, necessary for the manufacture of each of the materials used in both construction systems. Table 1 presents the emissions in CO_2-e total per kg of the indicated material. The main materials of traditional and industrial systems, which correspond to over 99% of its composition, are presented only.

Table 1: GHG emission factors of building materials used in Colombia. Source: (UPME et al. 2012)

Material	CO_2 emissions Total [ton CO_2-e/kg]
Fine aggregate	0,000021
Sand	0,000010
Wet cement	0,001185
Base	0,000013
Tiles	0,000830
Steel	0,002705

Whereas each construction system has a different composition in terms of the amount of materials required, it is necessary to know the detailed composition of each system and its weight per m^2. Table 2 breaks down the materials most used by systems and presents its contribution by weight (t / m²) and percentage to the system configuration.

Table 2: Most commonly used in building systems in Colombia materials. Source: (UPME et al. 2012)

	Construction system			
	Conventional masonry		Industrialized	
Materials	t/m²	%	t/m²	%
Fine aggregate	0,625	26%	0,5422	42,70%
Sand	0,734	30,50%	0,44521	35,10%
Wet cement	0,306	12,70%	0,15674	12,40%
Base	0,373	15,00%	0,0466	3,70%
Tiles	0,358	14,90%	0,03998	3,20%
Steel	0,009	0,40%	0,0267	2,10%
Total	**2,405**	99,5%	**1,23073**	99,20%

To carry out the quantification of waste generation, it was taken as reference the baseline for Public Policy of Sustainable Construction for the Aburrá Valley, indicating that traditional building systems, produce high levels of waste, generated by material waste caused by the lack of dimensional coordination in design. It is estimated that for every square meter built 1,35 m³ of waste is generated, from which, an average 0,35 m3 correspond to material waste, the equivalent weight of 0,50 t / m² built, most recyclable part. The remaining residues consist primarily of earth excavation (Quintero et al. 2006).

The partial plan of Sevilla, urban renewal plan recently developed by the urban development company (EDU) of the Municipality of Medellin, is taken as a case study. The instrument of urban planning aims to develop a sector of great importance for the city, in its strategic location within the metropolitan area known as service broker and a district defined as innovation and technology for the city character. This city plan is designed to intervene in an area that currently is occupied by low-density housing, auto repair shops and small-scale trade.

The total area of intervention, proposed in the plan is 155.934 m², distributed between 81.665 m², currently built, and 74.270 m² of public space, among streets, sidewalks and a park of great cultural and historical impact for the sector.

According to the provisions of the technical support document for the partial plan of Sevilla, the total net area to build, adding each of the 20 units of action (Block) that make up the polygon, is 77.372 m², area that it is defined an use in m², constructible in height, according to the distribution of applications in each of the units, as seen in Table 3.

Table 3: Densification rate in m² for units of action (Bloks). Source: (Empresa de Desarrollo Urbano 2010)

m² for building						
Block	**Housing**	**Large scale trade**	**Medium -scale trade**	**Petty trade**	**Services**	**For block**
1	5.534	-	1.230	615	4.919	12.298
2	8.070	-	1.793	897	7.174	17.934
3	8.984	-	1.996	998	7.985	19.964
4	13.032	1.448	1.448	1.448	11.584	28.960
5	13.871	1.541	1.541	1.541	12.330	30.824
6	11.530	-	1.153	1.153	9.224	23.060
7	14.031	-	877	877	1.754	17.539
8	10.207	-	638	638	1.276	12.758
9	6.152	-	384	384	769	7.690
10	2.842	-	237	474	1.184	4.736
11	-	-	676	676	5.411	6.764
12	4.692	521	521	521	4.171	10.428
13	3.713	-	309	307	1.856	6.188
14	8.738	-	546	546	1.092	10.922
15	8.905	-	557	557	1.113	11.131
16	10.292	-	640	640	1.280	12.796
17	5.180	576	576	576	4.604	11.511
18	-	18.003	-	-	3.251	16.254
19	18.292	2.415	2.415	2.415	10.975	36.584
20	10.647	-	665	665	1.331	13.309
Total	**164.656**	**19.504**	**18.203**	**15.930**	**93.284**	**311.650**

On the basis of this information corresponding to the m² total area to be built, **311.650 m²** in the partial plan, you can apply the emission factors of CO_2 and GHG produced by the manufacturing, transport and extraction of the raw material of the necessary things for construction, taking into account the two analyzed building systems, besides the production of waste or debris generated in the construction stage.

RESULTS AND DISCUSSION

Figure 1 shows that each of building systems analysed consumes a different amount of materials in its composition. It is established by this information that each built square meter in **conventional masonry has an average weight of 2,4 t/m²**, compared to **1,2 t/m², weight per built square meter of industrialized system, equivalent to a 47% less.**

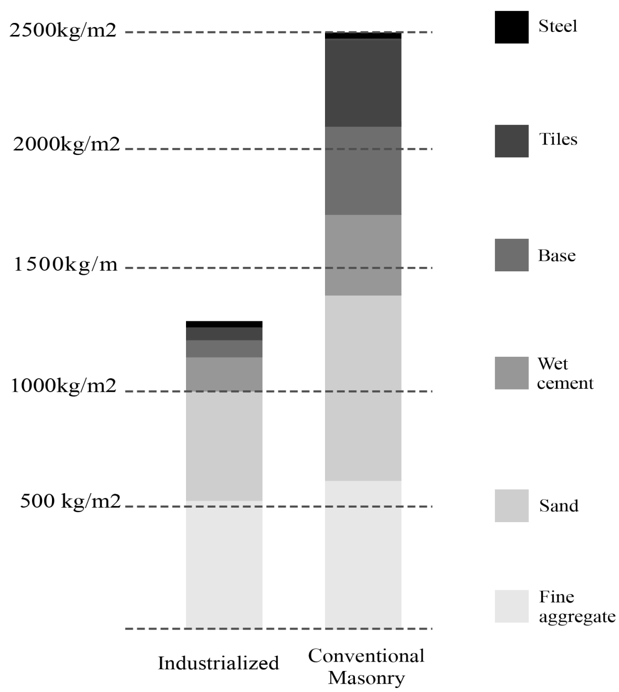

Figure 1: Consumption materials for building system

Capital consumption energy is an important item in the study of materials and efficiency of construction processes, in terms of air emissions and transport in the urban metabolism. These determinants have environmental considerations, aimed at reducing the impacts of construction and the possibility of raising strategies of mitigation or compensation, which can be integrated as factors for sustainable design. (UPME et al. 2012)

Systems emission quantification and its application in the case study.

The emission factors, generated by the manufacture of each of the materials composing the building systems, were applied according to the equivalent in weight of each one within the system, calculating total emissions per material and defining that way, the carbon footprint per m^2 of each building system.

In the case of traditional construction system, total emissions of 0,51 t CO_2-e / m^2 are quantified, according to Table 4.

Meanwhile, in the industrialized building system (walls cast in concrete or prefabricated), we find that this system generates emissions corresponding to a 0,31 t CO_2-e/ m^2, as shown in Table 5.

Table 4: GHG emission factors of building materials per m^2 built with confined masonry.

CO_2 emissions with conventional masonry construction				
System composition			**CO_2 emissions [t CO_2-e/t]**	**CO_2 emissions Total [t CO_2-e/m^2]**
Materials	**t/m^2**	**%**		
Fine aggregate	0,625	26%	0,02	0,01
Sand	0,734	30,5%	0,01	0,01
Wet cement	0,306	12,7%	1,19	0,36
Base	0,373	15,0%	0,01	0,01
Tiles	0,358	14,9%	0,83	0,29
Steel	0,009	0,4%	2,71	0,02
Total	2,405	99,5%	4,76	0,51

Table 5: GHG emission factors of building materials per m^2 built with industrialized system.

CO_2 emissions with industrialized construction				
System composition			**CO_2 emissions [t CO_2-e/t]**	**CO_2 emissions Total [t CO_2-e/m^2]**
Materials	**t/m^2**	**%**		
Fine aggregate	0,542	42,7%	0,02	0,01
Sand	0,445	35,1%	0,01	0,01
Wet cement	0,157	12,4%	1,19	0,19
Base	0,047	3,7%	0,01	0,00
Tiles	0,040	3,2%	0,83	0,03
Steel	0,027	2,1%	2,71	0,07
Total	1,231	99,2%	4,76	0,31

Applying these emission factors, to data on m^2 built in the partial plan, to the amount of materials used in the traditional construction system (confined masonry), you have that GHG emissions, associated with the life cycle of building materials, increases to **158.941t CO_2-e.** Keeping in mind, that the urban plan aims to develop in stages in an estimated 16 years' time, you can determine that in a year, it will be producing **9.933t CO_2-e**, equivalent to emissions from 5,040 vehicles mobilized daily in the Aburrá Valley for a year.

By contrast, in the case of industrialized system, GHG emissions correspond to a total of **93.495 t CO_2-e** by the total urban plan, **41,2%** less than the emissions produced by the traditional system of confined masonry. It is important to note, that these data only consider the production of materials, therefore, it has not been quantified the reduction of emissions from transport, waste construction disposal, operation of machinery at work and suitability of the soil.

According to the record of Environmental Archive AMVA, in the Aburrá Valley, there are over 300 companies that generate pollutant discharges to the atmosphere, these are classified into twelve sectors, of which four are directly related to the construction sector: the production of glass and ceramics industry, the metal manufacturing industry, the industry of petroleum elements and the processing industry of wood.

These four sectors equivalent to 30% of the industries in the Aburrá Valley and contribute 35% of the emission sources in the metropolitan area. Ceramic industries and glass, are those that provide the highest emissions of pollutants and greenhouse gases, compared to other productive sectors.

With respect to the total emissions from stationary sources, industries associated with construction contribute 27%, 39%, 15%, 5% and 22% of emissions of CO, NOx, SOx, VOC and PM2.5 respectively. Related to the production of materials for the construction industry, has a low contribution to the direct GHG emissions, within the Aburrá Valley, represented only 6% of emissions (Área Metropolitana del Valle de Aburá 2013).

However, the carbon footprint of building materials is high. The inventory of direct GHG emissions, being done currently, doesn't have in to account the emissions from mining activities and manufacturing, related to the production of building materials, when it takes place outside the Aburra Valley. When an analysis of this aspect is made, under a life cycle approach, the contribution of construction materials to GHG emissions is very significant (AMVA & UPB 2015).

Quantification of demolition and construction waste in the case study

According to the data of site characterization, developed in the technical document for Sevilla partial plan, they must be demolished a total of 108.805m^2, existing to give rise to new construction. This equates to approximately 129.472 tons of rubble, considering that per m^2 demolition of a construction built in a traditional building system (confined masonry) 0,85 m^3 of debris are generated (Morán del Pozo et al. 2011). On the other hand, the materials waste, because of new constructions, considering that per m^2 built, 0,5 tons of waste are generated, and this would add 155.825 tons of additional waste, by 311.650 m^2 to be built according to the plan. Under the traditional model of waste management, these would be deposited entirely in waste dumps, the vast majority without proper environmental management.

According to the public policy, of sustainable construction for the Aburrá Valley, losses or waste, resulting from inefficient work processes and the lack of modular design, in building systems in confined masonry, are reduced by at least 52%, relating to the amount of material and the total weight of each m^2, in an industrialized system. In addition, it should be considered, that this system uses emptied bearing elements, such as walls, concrete screens or prefabricated modules that do not generate the same amount of waste in traditional masonry walls. Therefore, a system of industrialized construction in total m^2 to build in the partial plan, it is possible to project a production of **74.796 tons of waste**, it means, **81.029 tons less of waste compared to traditional system.**

It should be emphasized, that the traditional waste disposal of demolition and construction, means a big problem in the city, as many of the slag heaps that receive all waste, operate informally and are not managed properly, causing major damages to the environment. (Ott 2006).

Then the scope of the potential for reducing emissions and waste generation, could be increased through the implementation of strategies for design and construction, involving even contributions to the energy efficiency of buildings, including the use of waste from demolition to produce new materials or construction processes input (Ott 2006), which could mean an additional reduction of 30% of the waste generated. Likewise, the modular coordination that allows the construction and assembly stage to be optimal, fast and economical, integrating different materials ((ICONTEC) 2013). Finally, a proper selection of materials, taking into account their physical properties, from bioclimatic parameters, allows the generation of satisfactory thermal, lighting and acoustic environments for users, and avoids excessive use of artificial conditioning systems, consuming large amounts of energy and producing polluting emissions into the atmosphere.

CONCLUSIONS

The regulatory plans of land management and urban development, in terms of planning, such as partial plans adopted by the regulation of Territorial Arrangement Plans as a planning strategy, should include those ones for sustainable construction, to evaluate the possibility of using new building systems and less polluting management models.

According to the conditions of population growth and urban development in the metropolitan area of the Aburrá Valley, and generally in all cities of the country, systems and measurement processes are necessary to reveal the environmental impacts and air emissions caused by construction and manufacturing or elements and materials processing.

It is possible to determine from the relation of existing and described data in this work, a potential reduction of polluting emissions to the atmosphere from the election of the constructive system, the sustainable materiality, the use of the demolition residues and the modular coordination in the design.

According to the results, the industrialized system generates 39% less CO_2 emissions and 52% less waste from construction than a traditional system. Taking these data to urban scale, applying them in the partial plan of Sevilla, which includes a total area of 155.934m^2 and intends to build in height a total of 311.650m^2, this means a reduction of emissions of 65.446 t CO_2-e, which correspond to that produced by 1965 cars circulating daily in the metropolitan area for a year; and 81.029 tons of less waste, which it would contribute to a sustainable model, with efficient management of resources and minimization of environmental impacts in the city of Medellin.

Although the effects of the current model of the construction industry can be demonstrated to the scale of a particular building, a larger one of urban form, gives the possibility of obtaining indicators more relevant and scalable than other urban developments in the city or in any plan of the country.

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