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Research Article

Construction and demolition waste in Tungurahua: A case study from Ecuador

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ABSTRACT

This research will make an analysis of the material stock in Tungurahua-Ecuador from 2013 to 2019 using the general purpose of six "s" of Brand (1994) for site, structure, skin and space plan layers, data was taken from the Instituto Nacional de Estadisticas y Censos (INEC), from 2013 to 2019; and for the stuff layer the research applied online forms, the results show that reinforced concrete is the predominantly material used in foundation, structure and skin layers, then bricks and blocks are most common used in space plan layer and timber elements are the most used in the stuff layer, finally the paper proposes some ways to deal with this type of materials and future information to be addressed in new research.

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INTRODUCTION

While the construction sector is often a very important driver for the economy in many countries, it is also the main global consumer of raw materials and is accountable for large amounts of waste and 25% to 40% of global emissions [1]. And yet less than a third of construction and demolition waste (CDW) is recovered in United States., see Figure 1.

In 2014, 541 000 tonnes of urban waste per day were produced in Latin America, this is expected to increase by 25% for the year 2050. In the region, 90% of urban waste is not repurposed [2]. However, when it comes to CDW there is no consistent data in the region and often each country manages information differently.

In Ecuador the production of urban waste is directly related to population density and to territories with higher business development which now have collapsed disposal systems [3]. The latest National Plan for Managing waste (PNGIDS) aimed at promoting the national recycling and energy industries and extending the responsibility to the producer and importer in the management of hazardous and special waste [4]. This is to be done by involving the local governments, base recyclers and the private sector and assigning about USD$27M to the project for 12 years, meaning that by 2021 solid waste in the country would be efficiently managed [4]. However by 2020 Ecuador still buried 94% of its waste and every municipality deals with it according to their capacity in the absence of national guidelines [3].

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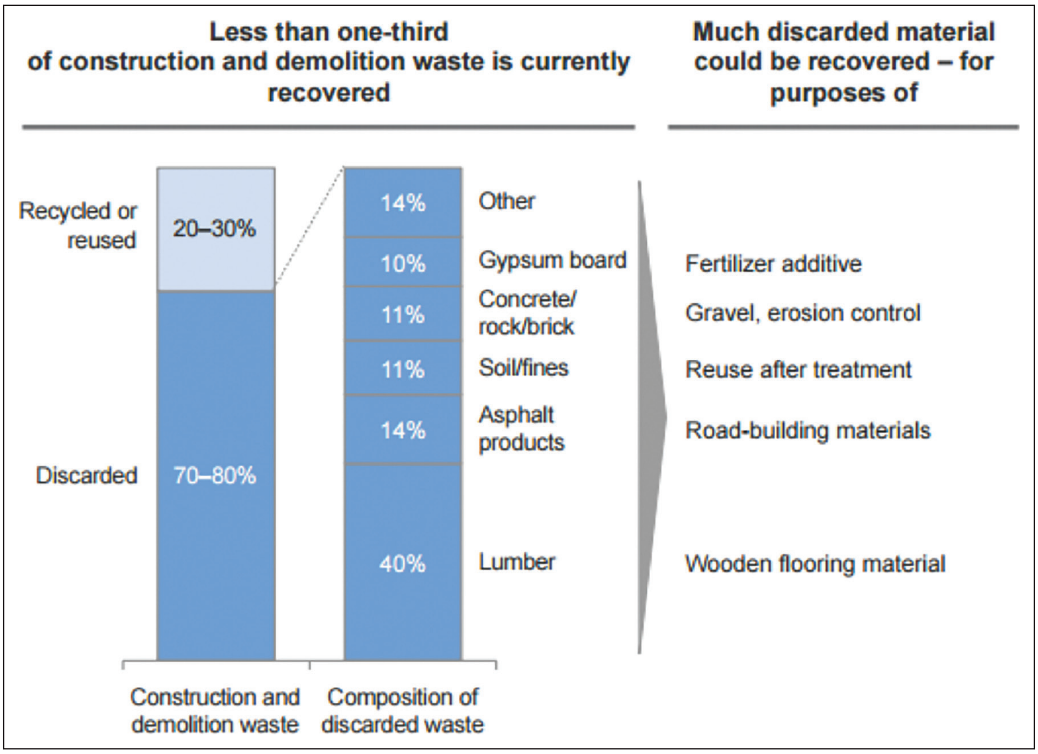

Figure 1. Amount of construction and demolition waste in the United States [1].

In Ecuador, 10 cities account for 70% of the national waste production, ranked according to the relation between population density and per capita waste production, Ambato ranked in third place with 1.29 kg/hab/day [3].

During 2019, Tungurahua construction industry contributed 2.1% to national incomes, where Guayas and Pichincha were the major contributors, 30.2% and 19.8% respectively, Ambato was the first state in Tungurahua contributing 82.8%, then, second Píllaro 7.5%, after, third Pelileo 3.8% and, fourth, Baños 2.3%. See Table 1.

Table 1. Construction industry aggregated value from Tungurahua in Ecuador [5]

States	Agregated value	Province contribution	National contribution
Ambato	205,347	82.8%	1.7%
Baños	5,725	2.3%	0.0%
Cevallos	310	0.1%	0.0%
Mocha	797	0.3%	0.0%
Patate	1,680	0.7%	0.0%
Quero	1,614	0.7%	0.0%
San Pedro De Pelileo	9,446	3.8%	0.1%
Tisaleo	4,313	1.7%	0.0%
Santiago De Píllaro	18,658	7.5%	0.2%

Literature Review: Circular Economy, Urban Mining, CDW Management and Research Framework

Circular Economy in Construction and Demolition Waste

Economic, organizational, technical, financial and cultural challenges have to be addressed to enable the circularity in the construction sector, in the economic field, material value and its uncertain prices into future and low prices at their end of life make uneconomically to reuse them. After, in the organizational aspect, lack of client awareness and unclear actors´ roles across building´s life cycle depending on circumstances of projects. Another challenge is related to the technical issues such as considering adaptability, flexibility and deconstruction [6]. Moreover, there are financial obstacles, such as the business approach that collaborate to the supply chain and circular business cases that reaffirm its feasibility [7]. Finally, there are cultural barriers depending on how solutions are well received and correctly utilized by users [8].

Circular economy in the construction context has little research [6] and its emerge is essential [9], short term and medium lived consumer goods have been targeted by the circular economy (CE) concepts forgetting long-lived products such as buildings, which are conformed by a variety of elements and materials that possess their own lifecycle, functions and characteristics are interacting each other at the same time in the entire building system [10], other sectors have explored business models about long-life structures but in the industry sector is lacking because of their value as material assets [6].

Urban Mining

Urban mining considers buildings as mines where stock and flow resources are important [11], annual stocks held in buildings may not vary over time nevertheless annual flows of materials may change considerably year to year depending on circumstances [12]. Materials are organized into buildings components and elements that determine an ease extraction or an availability for collection [11].

Materials lifespan makes complicated to decipher when a material will be available, detailed information such as bills of materials in combination with construction types would help to know quantities and material types, also, building information modelling (BIM) with waste management improves precisely waste predictions [11].

Stephan and Athanassiadis [13] proposes in their work an estimation, spatialization and quantification manner for inflows and outflows associated with replacement of construction materials in order to maintain urban building stocks. Their study is based on archetypes of possible assemblies, datasets, census of land use and employment that includes floor areas, year of construction and number of stories for around 14385 buildings.

Construction and Demolition Waste Management

Countries have tried to improve the construction and demolition waste (CDW) management by encouraging behaviours, implementing laws, motivating plans or creating taxes, eg., in Australia, deconstruct old timber houses is a common practice, the country has an estimated 80% of materials recovered and reused for renovation and remodeling of existing homes or in the construction of new replica housing. In the Netherlands, a strict government regulation states that dumping reusable waste is prohibited, this regulation generates an 80% of CDW reused in other construction generally in creating materials for road base. In Norway, a plan for design for deconstruction that dismantle building systems, relies on local building materials and simple traditional technology, the components are easily assembled and have the capability of easily changed or reconfigured. In United Kingdom, a landfill tax introduced in 1996 that incur rates depends on separated or mixed waste, £2 or £11/tonne respectively, this tax has contributed to a big increase of fixed and mobile crushing and recycling sites [7].

Research Framework for Construction and Demolition Waste

Three framed levels for CE research in the built environment are proposed consisting on macro (cities and neighbourhoods), meso (buildings) and micro (assemblies and components), and six fundamental dimensions are considered to achieve more circular buildings, there are environmental, technological, economic, societal, governmental and behavioural dimensions [9].

Materials are uncapable to be recovered because its replacement is always linked to demolish, this happens because, they are often part of an integrate fixed assembly, so most of the parts when a building ends its life cycle they are demolished and wasted with the entirely building, moreover, material's 'technical life cycle' is longer than their 'use life cycle' [14], so, some materials could be still used but the difficulties to be separated from other parts makes it complicated.

Various authors have developed guidelines for Design for Deconstruction DfD, for example Scot Fletcher classifies a total of 37 guidelines into three levels: systems, product and material level. Berge describes three principles: separate layers, possibilities for disassembly within each layer and use of standardized monomaterial components. Thormark postulates 18 design guidelines into three groups: choice of materials, design of construction and choice and connections. Sassi gives two main areas: the process of removal of building elements and materials from building structure and the requirements for reprocessing of building elements and materials to enable reintegration in a new building. Crowther proposes five generative fields: industrial design, architectural technology, buildability, maintenance and research. Addis and Schouten presents 19 principles into these outcomes: component reuse, component manufacture and material recycling. Durmisevic lists 37 guidelines relate to three levels: building, system and material level in a scenario between use life cycle and technical life cycle [15]. Overall aim is material resource efficiency through facilitating reuse and recycling.

As we have shown, fields studied about construction components are dispersed, there are many principles from different authors nevertheless Nordby et al. [15] characterise and classify them in three groups: behavioural statements, performance standards and prescriptive guidelines. They create a multi-purpose system based on design guidelines in order to be an assessment tool to be used when selecting buildings components for a new design with respect to their potential at the stage of deconstruction and applied in two cases studies of wood components and bricks.

Sassi [9] also develops a criteria for establishing suitability for recycling, down cycling, reuse as new and as second hand item, and apply it into floor finishes. The study shows different types of floor coveries and determined that solid wooden floor nailed have the highest score into the recycling category, rubber interlocking floor tiles loose laid have the best score to be down cycled, steel covered HDF raised floors screwed to plinths with loose laid carpet tiles have a high value for being reused as new, and, finally, carpet tiles loose laid and rubber interlocking floor tiles loose laid possess a high score for being reused as second hand item.

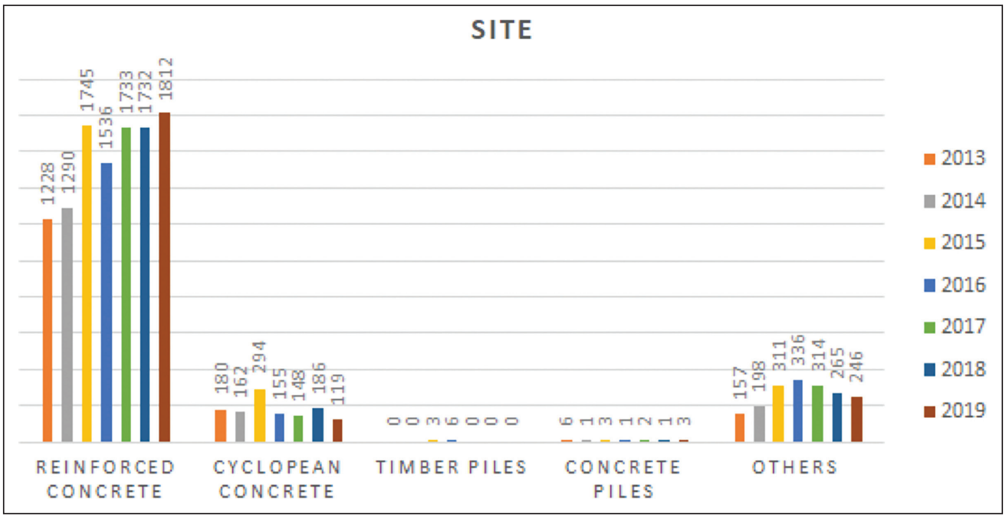

Figure 2. Site layer in Tungurahua from 2013 to 2019 [16].

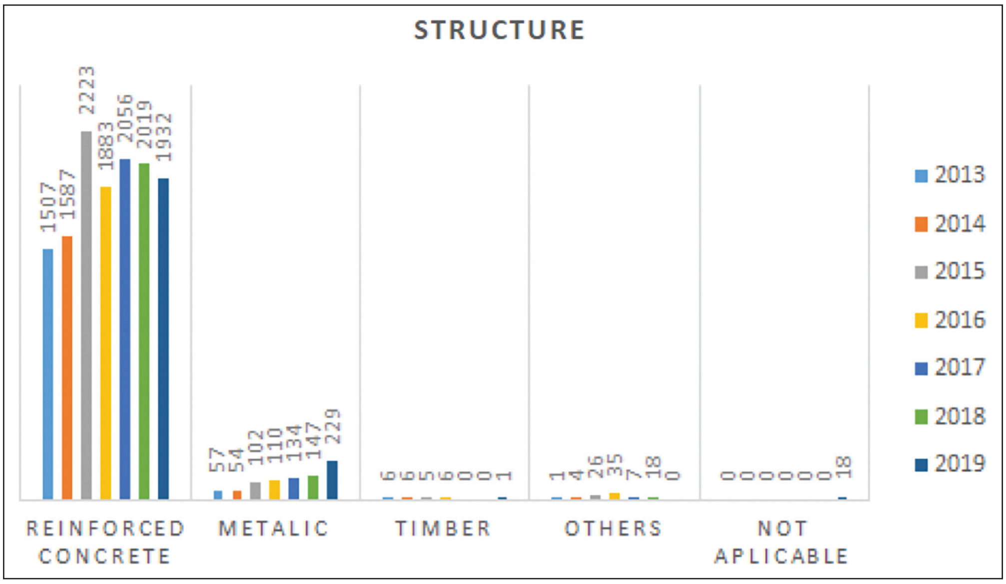

Figure 3. Structure layer in Tungurahua from 2013 to 2019 [16].

MATERIALS AND METHODS

This study is a descriptive quantitative research. The research uses public data from Instituto Nacional de Estadísticas y censos (INEC), specially related to the building survey done from the years 2013, 2014, 2015, 2016, 2017, 2018 and 2019. In the website there is no more data available about years 2020 and 2021 [16]. Also the project collect data from 104 people mainly from Ambato, they were asked to fulfill an online form by a massive message sent through whatsapp.

In overall the research took the general purpose of six "s" of Brand (1995): site, structure, skin, services, space plan and stuff [17]. For the site, structure, skin and space plan layers, data was taken from the Instituto Nacional de Estadísticas y censos (INEC). Data was compressed into four graphics divided by site, structure, space plan and skin layer. For the stuff layer the research applied an online form in order to discover the materials used in floor finishes, dinning furniture, doors and windows.

RESULTS

In the site layer most buildings have used reinforced concrete, others materials and cyclopean concrete, is not so common the use of timber and concrete piles as can be seen in Figure 2. The structure layer is made of reinforced concrete in most buildings, also the use of metallic structures have increased and the use of timber is not so common as can be seen in Figure 3. The space plan layer is constituted

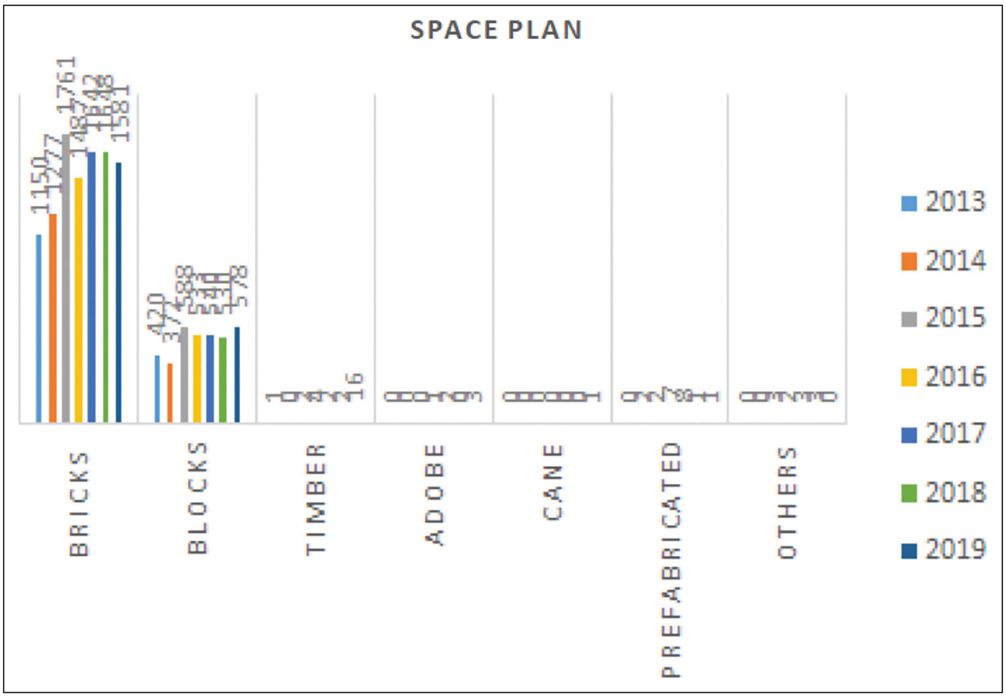

Figure 4. Space plan layer in Tungurahua from 2013 to 2019 [16].

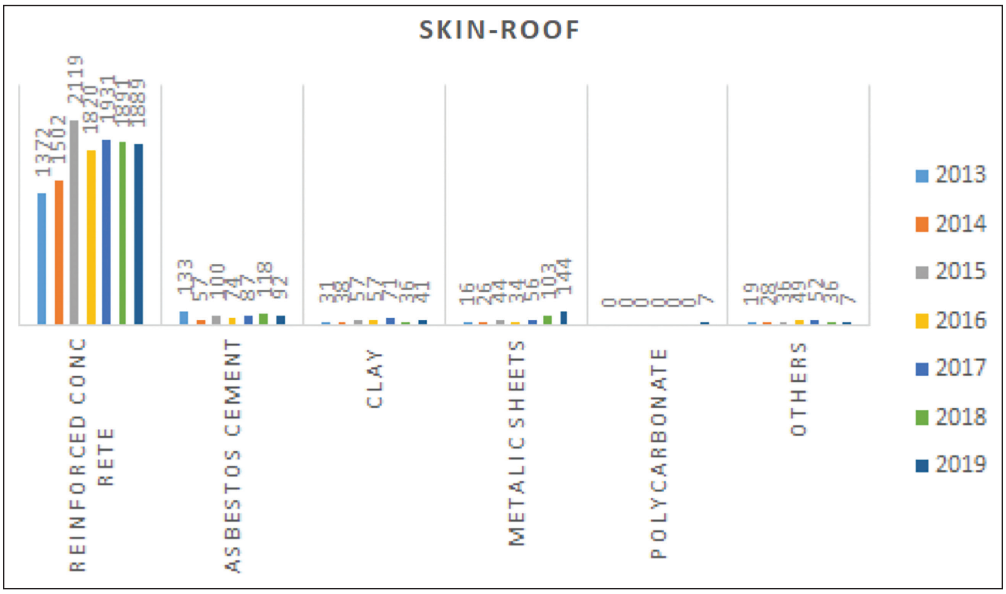

Figure 5. Skin layer in Tungurahua from 2013 to 2019 [16].

by bricks and blocks in most buildings, the use of timber, adobe, cane and prefabricated is not so common, as can be seen in Figure 4. The skin layer is conformed by reinforced concrete in most buildings, the use of asbestos cement, clay, metallic sheets and polycarbonate are not so common, as can be seen in Figure 5.

According to the report of predominant materials from INEC (2019) Tungurahua province has a total of 2180 buildings, from this total, reinforced concrete is the most common material used in foundation, structure and roofs, 1812 buildings used reinforced concrete in foundation, as can be seen in Figure 2; 1932 buildings used reinforced concrete in structure, as can be seen in Figure 3 and 1889 buildings used reinforced concrete in roofs, as can be seen in Figure 5. In the case of walls, 1581 buildings used bricks (apparently clay), then 578 buildings used blocks (apparently concrete), 16 buildings used wood, 3 earth, 1 used cane and 1 prefabricated components, as can be seen in Figure 4.

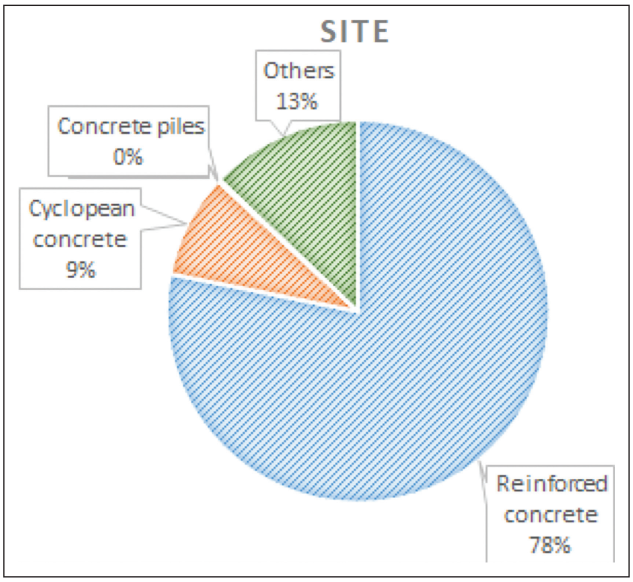

Figure 6. Percentage of buildings in Tungurahua according to the materials used in site layer from 2013 to 2019 [16].

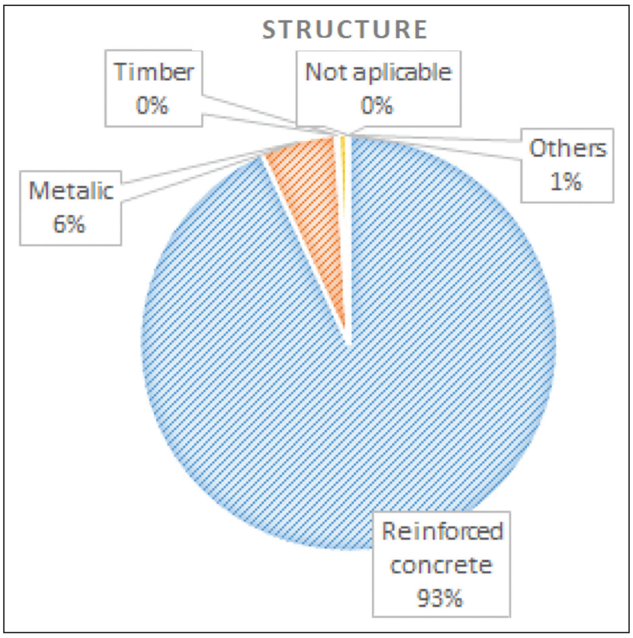

Figure 7. Percentage of buildings in Tungurahua according to the materials used in structure layer from 2013 to 2019 [16].

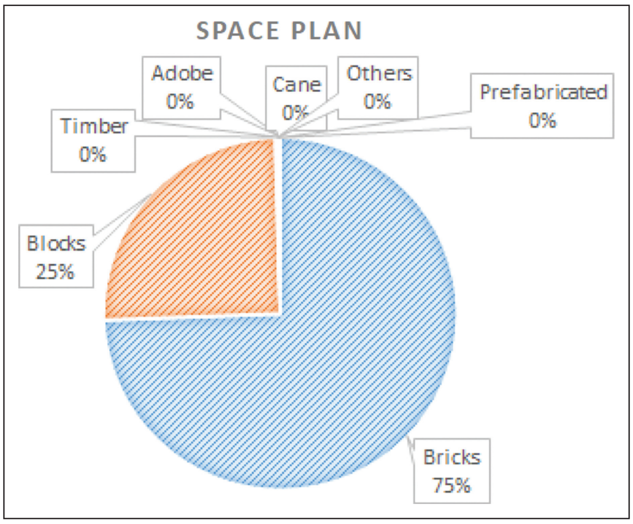

Figure 8. Percentage of buildings in Tungurahua according to the materials used in space plan layer from 2013 to 2019 [16].

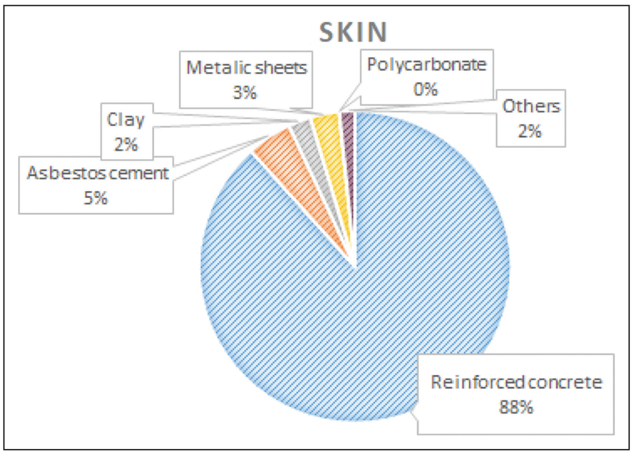

Figure 9. Percentage of buildings in Tungurahua according to the materials used in skin layer from 2013 to 2019 [16].

From 2013 to 2019, 14173 buildings have been created, in the site layer, 11076 buildings used reinforced concrete that represents 78%, just 1244 used cyclopean concrete representing 9% and other materials not specified represent 13%, as can be seen in Figure 6. In the structure layer, 13207 buildings were built using reinforced concrete, representing 93% and just 833 buildings used metallic structure representing 6%, as can be seen in Figure 7. In the space plan layer, 10546 buildings used bricks, representing 75% and 3561 buildings used blocks representing 25%, as can be seen in Figure 8. Finally in the skin layer, 12524 buildings were built using reinforced concrete, represents 88% and just 661 buildings used asbestos cement, representing 5% and 423 metallic sheets, representing 3%. Clay and others materials represent 2% correspondingly, as can be seen in Figure 9.

For the stuff layer, 104 people contributed with the analysis, as can be seen in Figure 10. Figure 11 shows that 50% of floor recoverings are made of wood, then 21.2% has floating floor, 15.4% ceramics, 10.6% porcelain, 6.7% cement, 1.9% vinil and carpet 1%. Figure 12 shows that 99% of doors are made of wood, 1.9% metal and 1% glass. Figure 13 determines that 98.1% of furniture is made of wood, 1.9% metal and 1.9% plastic. Windows frames are mostly made of aluminium (58.7%), 26% are made of iron, 18.3% are made of wood and 1% of plastic, as can be seen in Figure 14.

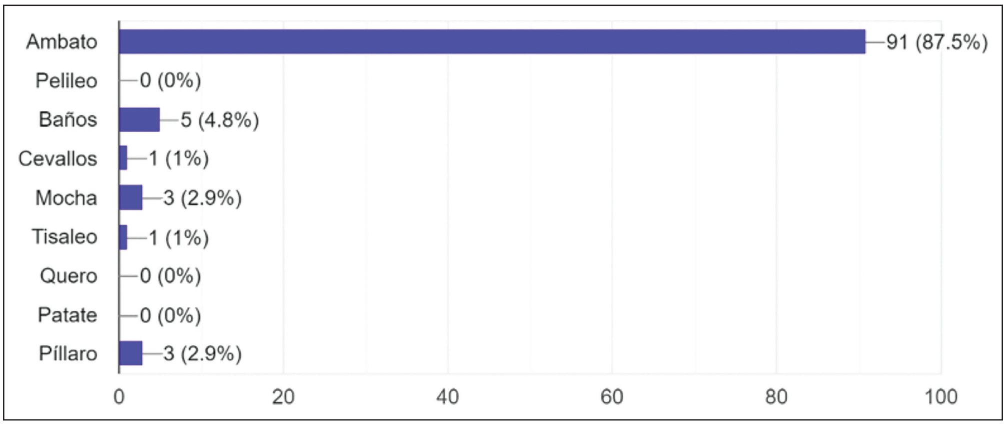

Figure 10. People in Tungurahua. Source: Online survey.

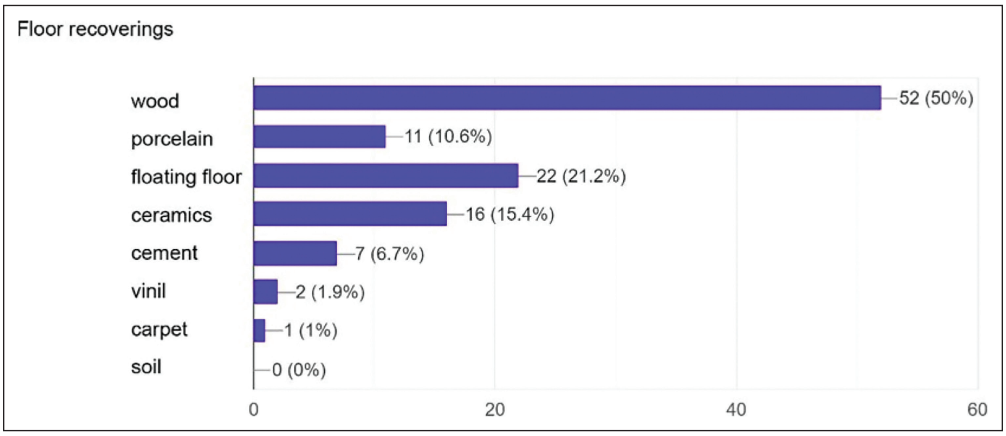

Figure 11. Floor covering in Tungurahua. Source: Online survey.

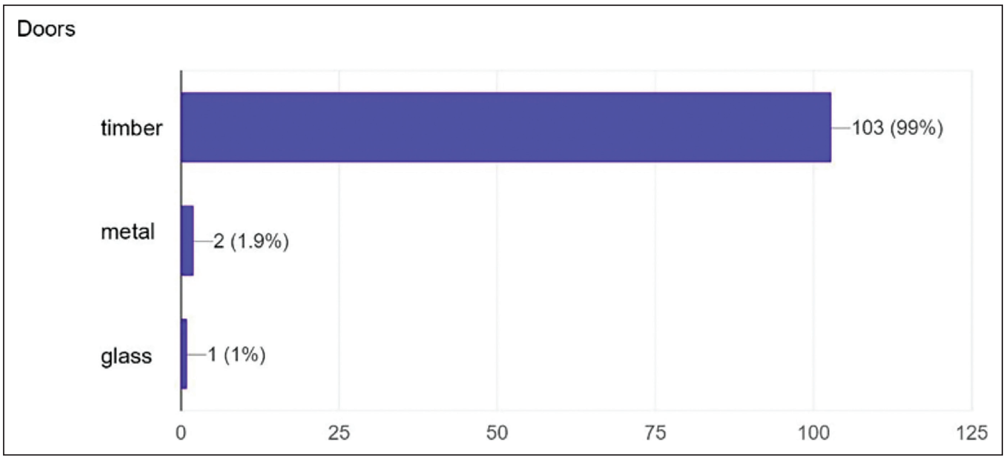

Figure 12. Doors in Tungurahua. Source: Online survey.

For behaviour tendencies the graphics show that most people do not waste any material from their homes, 51.9% do not throw away any element, 22.1% have wasted floor coverings, 15.4% furniture, 13.5% windows, 5.8% doors and 4.8 ceilings, as can be seen in Figure 15. Figure 16 shows that 38.5% would include second hand furniture, 37.5% prefer to not include any item, 19.2% doors, 11.5% windows, 10.6% floor covering, and 5.8% ceilings. Figure 17 shows that 49% of people would donate items, 41.3% will recycle, 20.2% sell and 15.4% will prefer interchanging.

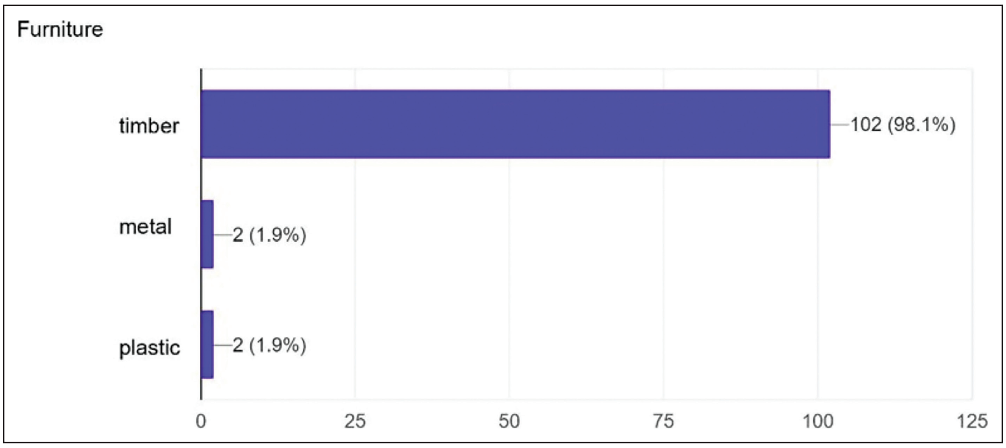

Figure 13. Furniture in dinning rooms in Tungurahua. Source: Online survey.

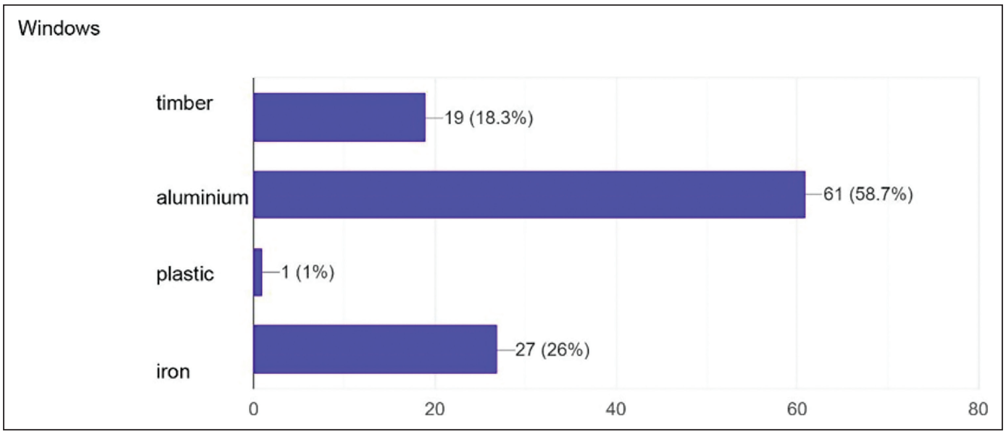

Figure 14. Frame windows in Tungurahua. Source: Online survey.

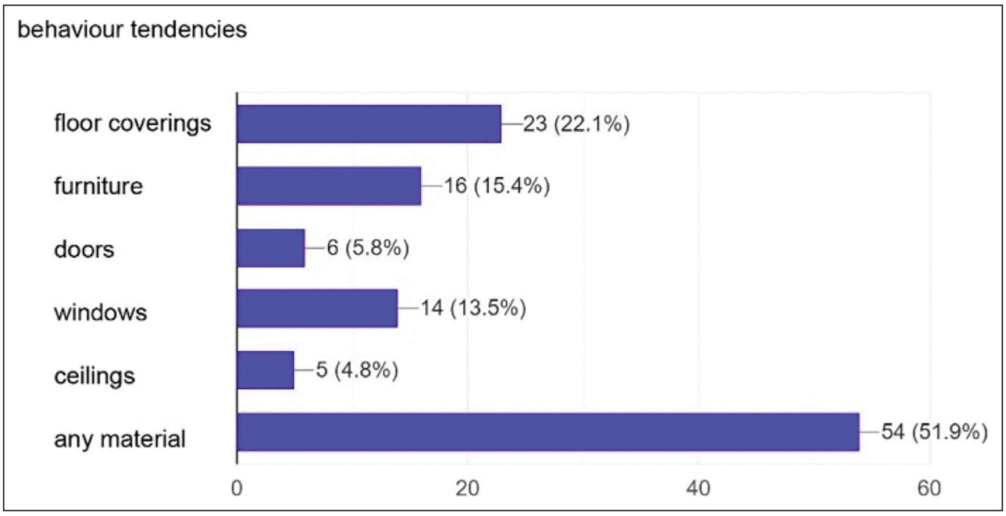

Figure 15. Elements wasted in Tungurahua. Source: Online survey.

DISCUSSION

There is no data related to the quantity of materials wasted, local government must know how much waste is being produced in order to size the capacity of any new disposal center. Nevertheless, the way that buildings are created could give a general background of what type of materials could be wasted in future, the construction sector defi-

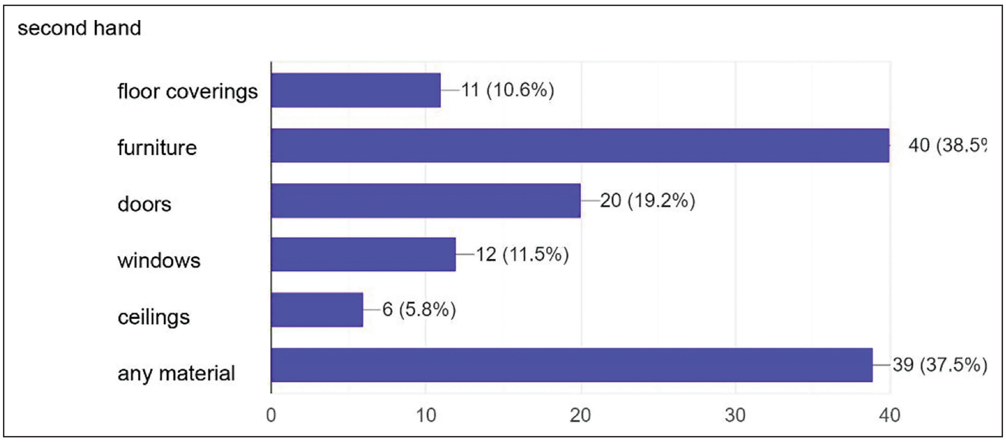

Figure 16. Elements that will be included in buildings in Tungurahua. Source: Online survey.

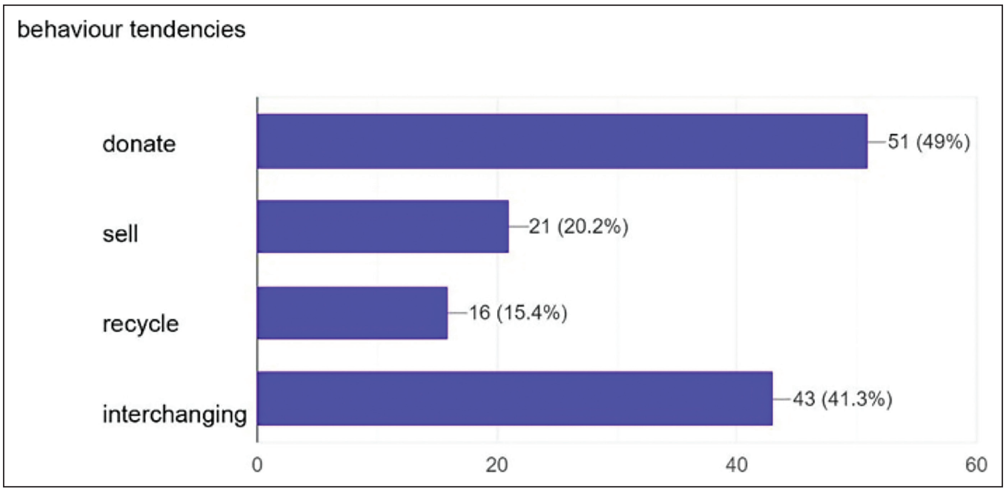

Figure 17. Actions instead waste in Tungurahua. Source: Online survey.

nitely has some re-usable and re-manufacturable materials such as timber elements from the stuff layer and some recyclable materials from site, structure and skin layers, the main goal will be to decipher when they are going to be available to the market.

The use of reinforced concrete as main material in foundation, structure and skin, and the use of bricks in space plan creates the possibility to introduce some centers for re-cycling into other elements such road bases [11]. Also, the use of timber elements as main element in the stuff layer in doors, furniture and floor coverings could allow implementing spaces for re-manufacturing and re-using.

CONCLUSIONS

From 2013 to 2019 the buildings in the Tungurahua province have as main material the reinforced concrete specially in the foundation (78%), structure (93%) and skin layers (88%), in the space plan layer the bricks (75%) and blocks (25%) are the principal materials used last years.

Timber floors (50%), doors (99%) and dinning furniture (98.1%) are the main elements inside households, in the case of windows frames there are made of aluminium in most buildings (58.7%). These elements could be considered as archetypes [13] in order to maintain building stocks.

On one hand, the fixed assembly of the reinforced concrete [14] founded in foundation, structure and skin layers makes uncapable to be easy recovered. On the other hand, timber floors, doors and furniture can generate a market for re-use of timber elements that include flexible and deconstruction strategies [6]. In the behavioural dimension [9], second hand furniture or donations could be promoted by implementing laws [7, 8].

More studies are needed to understand the design process of existing buildings and the possibilities for disassembly elements especially for the predominant timber elements in household. Moreover, another way to determine quantity of wasted materials and illegal debris disposals could be by addressing local recyclers. Finally, the stuff layer definition and behavioural dimension could include more people from other parts of the province.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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