Use of GIS and BIM tools in determining the Life Cycle impact of urban systems. Case study: residential buildings which apply the Eco-Efficiency Matrix in the City of Quito, Ecuador.

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ABSTRACT: Of the numerous effects of human activity with a direct impact on changes in the environment, one of the main activities is construction, which generates approximately 33% of CO2 emissions into the atmosphere and contributes to an increase in environmental impact.

At present, interest in reducing these emissions has led to the development of various tools to quantify, evaluate and control environmental impact. Among the better-known ones, Life Cycle Analysis (LCA) is frequently linked to BIM modelling.

The cities are responsible for 75% of carbon emissions, for that reason, this paper aims to analyse whether urban concentration of high-rise blocks. Using the GIS tool to geographically visualize the urban system of the study area, the main displacement routes were located according to the types of transport used and the location of two study sites in the Hypercentre of Quito considered as points of origin for these trips. These data were entered in several tables to ascertain the overall impact in the use phase at city level. The impact of the building in the production, construction, de-construction and recycling phases was added at a later stage.

The use of the three tools - LCA, BIM and GIS - allowed us to establish that the highest number of impacts occurs in the use phase, given the high consumption of operational energy.

Finally, it was concluded that in Quito, a city model concentrated in height, displays less environmental impact compared to uncontrolled urban extension. It is therefore essential to locally implement tools, such as the Eco-Efficiency Matrix, which contribute to the sustainable development of the city.

KEYWORDS: Life Cycle Analysis, Geographical Information System, Building Information Modelling, Eco-Efficiency Matrix, Urban concentration.

1. Introduction.

The city is the space where people develop their main activities, such as: live, work, rest, have fun, circulate and interact (Sarrande Cobos, 2013), so that it is essential to establish an environmental balance between citizens and their surroundings.

In recent decades, the urban debate has implemented new themes such as the environment, citizen security, public space, sustainable mobility, gender studies, among others, which directly influence the socio-spatial configuration of a city (Montúfar Córdova, 2008), and that affect urban systems, because cities vary according to their hierarchy and the functions that will be developed in them. The urban system at the disposal of cities is understood as the territory and the relationships they have with each other and with their environment based on various flows responsible for articulating a city, such as: transportation, the network of parks and forests located in the urban fabric, road networks, squares, various types of equipment, natural, economic, social components, etc. (Erazo Espinoza, 2009).

Nowadays, there is limited research available regarding emissions relating to infrastructure and occupant activities at urban level while numerous studies have focused on modelling and LCA at building level. This is partly due to the poorly defined system boundaries; quantification of the complex effects between buildings; availability of comparable data; integrated modelling; and the uncertainties relating to the occupants' lifestyles. (Bin Huang, 2017). At urban level, few studies have applied LCA as part of their methodology. In fact, in the last decade, Life Cycle Analysis methodology – as applied to buildings - has been greatly developed, both in terms of methodology and practice (Rashid and Yusoff, 2015; Anand and Amor, 2017; Geng et al., 2017; Ingrao et al., 2018; Mastrucci, Marvuglia, Leopold, et al., 2017; Nwodo and Anumba, 2019; Ortiz, Castells, and Sonnemann, 2009; Roberts, Allen, and Coley, 2020; Saade, Guest, and Amor, 2020; Thibodeau, Bataille, and Sié, 2019; Zeng and Chini, 2017). In effect, the use of BIM platforms in the representation of buildings and their integration into environmental assessment processes is an area that is considerably advanced. (Abbasi and Noorzai, 2021; Bueno and Fabricio, 2018; Hollberg, Genova, and Habert, 2020; Lu et al. 2021; Najjar et al., 2017; Röck et al,. 2018; Santos et al., 2019; Santos, Aguiar Costa, et al., 2020; Santos, Costa, et al., 2020; Soust-Verdaguer, Llatas, and García-Martínez, 2017; Tushar et al., 2021).

In the last five years, there has been growing interest in exploring the potential of GIS platforms to facilitate the evaluation process of environmental impact from territorial or urban variables. Many of these studies focus on the impact of transport on certain activities, such as waste management (Blengini and Garbarino, 2010; Ferronato et al., 2020; Li et al., 2020; Mastrucci, Marvuglia, Popovici, et al., 2017), the transportation of components for manufacturing (Göswein et al., 2018) or food distribution chains (Loiseau et al., 2020). In any case, currently, most of the studies combining GIS and LCA focus on the evaluation of various alternatives to bioenergy production on a territorial scale (Aalto et al., 2019; Clarke, Sosa, and Murphy, 2019; Cong et al., 2017; Gasol et al., 2011; Hiloidhari et al., 2017).

However, there is still limited research on the integration of BIM and GIS platforms into the Life Cycle Analysis of urban complexes, beyond the understanding of urban space as an aggregate of buildings (Mastrucci, Marvuglia, Leopold, et al., 2017).

Thus, several of the authors mentioned above have provided some basic guidelines for working on LCA at urban level from a sustainability perspective, as cities are the main sites for the promotion of sustainable development, given their sizeable contribution in generating positive and negative environmental impact through their internal activity (Alberti et.al, 2019).

Researchers such as Bin Huang, Ke Xing and Stephen Pullen have developed an integrated Life Cycle Analysis model to support the evaluation of the carbon footprint at urban scale. This urban model considers associated, incorporated, operational and travel carbon emissions, as well as taking into account carbon offsetting from solar energy use (Bin Huang, 2017).

Considering that only 3% of the planet's territory is occupied by cities, they consume between 60 and 80% of energy and generate around 75% of carbon emissions. For this reason, it is essential to effectively establish land use planning measures, to increase the involvement of inhabitants in improving their environment and to promote sustainable economic activities. (Programa de las Naciones Unidas para el Desarrollo Ecuador, 2016).

Moderately high-density cities are more efficient and can reduce resource and energy consumption; Unlike urban sprawl, which is one of the negative actions that is causing inconvenience to the supply of fresh water, livelihoods, and public health. (Programa de las Naciones Unidas para el Desarrollo Ecuador, 2016).

The environmental impact of urban dispersion is particularly apparent in the increase of the carbon footprint as increased travel results in higher energy consumption. Hence the statement by Edward Glaeser, that people be able to live in high-rise buildings where the elevator is the protagonist and not in areas of uncontrolled expansion where car use is prioritized. (Glaeser, 2011).

To tackle this serious problem, the municipality of Quito drew up a roadmap, Vision of Quito 2040, along with a New City Model, with a particular interest in meeting the SDGs[1] through the recommendations made during the Habitat III Conference held in Quito (Ecuador) in 2016.

Approximately 30 years ago, the population of the QMD[2] was 893,000 inhabitants and the city occupied an area of 16,297 hectares with a density of 55 inhabitants / hectare. At present, the population and urban expansion have almost tripled with a population density similar to that mentioned above. Therefore, this current low density reflects the dispersion of people in the territory, where space has been occupied both formally and informally, making displacement more difficult and greatly increasing the cost of the provision of equipment, infrastructure and services. This in turn results in an expensive city with large areas of vacant land (Instituto Metropolitano de Planificación Urbana de Quito, 2018).

This dispersion of the city causes several negative effects both in economic and functional terms. The disorderly and hasty expansion of the urban area has led to territorial chaos, where physical and social deficiencies, low quality of buildings, poverty and

[1] SDG: Sustainable Development Goals
[2] QMD: Quito Metropolitan District

marginalization are evident. (Instituto Metropolitano de Planificación Urbana de Quito, 2018)

Currently, the municipality of QMD has encouraged sustainable construction through the implementation of the Eco-Efficiency Matrix, which aims to promote a compact city based on the concept of Transportation-Oriented Development (TOD). That is to say, it is promoting the densification of the city following the public transport axes of Fast Transit Buses (FTB) and the Quito Subway (underground line).

Given that nowadays many people have become accustomed to travelling long distances with transfer trips, due to the urban and population expansion observed in Quito, trips with transfers represent a third of the total trips per day (Bastidas-Zelaya and Ruiz, 2016). However, this situation may change with the TOD currently being promoted with the Eco-Efficiency Matrix. As the city follows a longitudinal morphological model, the densification of the space is promoted in order to ensure its sustainability in urban-architectural terms so that potential building may be stimulated gradually through eco-efficient building designs (Secretaría de Territorio, 2017).

Although the Eco-Efficiency Matrix aims to consolidate certain parts of the city, it is crucial to ascertain the environmental impact of this process in order to determine the extent of its possible sustainability. Therefore, a Life Cycle Analysis (LCA) at urban-architectural level has become essential in order to establish whether the increase in height aids the reduction of CO2 emissions.

The main area where the greatest increase in height is allowed is the North Hypercentre[3], where the greatest amount of movements is observed. The two case studies were located here in order to link the LCA use phase, calculating the impacts of the displacements

[3] Hypercentre: sector where the largest amount of public and private urban facilities is concentrated. It is the economic-financial centre of Quito, since the largest sources of work are located there.

made by the users of the model with the impacts generated by the building in the phases of production, construction, de-construction and recycling. Thus, the aim was to establish whether the city was more sustainable when concentrating buildings in height rather than spreading out the urban system.

This research aims to develop a LCA method to determine whether urban concentration reduces the environmental impact in Quito, using GIS and BIM tools at urban level in the Hypercentre area of the city.

2. Methodology.

The method proposed applies the BIM-LCA and GIS-LCA tools to the case study of the Quito Hypercentre to assess whether urban concentration reduces environmental impact.

The application of LCA in the field of construction makes it possible to examine the definition of the system limits, data sources, phases of the life cycle included, and the environmental impact indicator calculated (Soust-Verdaguer, Llatas and García Martínez, 2016).

The LCA application follows ISO 14040 (UNE-EN ISO 14040) 2006), ISO 14044 (UNE-EN ISO 14044 2006) and EN 15978 (UNE-EN15978 2012). The method consists of four main phases: scope and goal definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation.

I. Scope and goal definition: the main goa lof this study was to if urban concentration reduces the environmental impact in the City of Quito, through the use of GIS and BIM tools in the Life Cycle Analysis at the urban level in the Quito Hypercenter area. The environmental impact categories and indicators included in the analysis were based on Galán-Marín et al. (2015) and Asdrubali et al. (2017). The authors identified the most relevant impact indicators to be taken into account in LCA building application, namely global warming potential (GWP). Therefore, the impact indicators calculated in this study is GWP.

II. System boundaries: according to the building system context, the most relevant LCA phases were selected based on EN 15978 (UNE-EN 15978 2012). Therefore, the stages considered in this study were production, construction and end-of-life. The life cycle was organised into three main phases, including different modules complying with the standard classification, as follows:

- Production phase, including raw materials (A1), transport of materials to the factory (A2) and manufacture (A3).
- Construction/deconstruction phase, including transport to the construction site (A4), the construction process (A5).
- Use phase including the use stages B1 to 7 were not included in the system boundaries as the case studies were ephemeral building systems. Several authors have focused their studies on embodied and operational energy over the entire life cycle (Langston and Langston, 2008). However, as operational energy throughout the use stage is not relevant, it is not considered in this paper. The study focuses on the design strategies and materials of the case studies analysed.

  The urban and local displacements of the study models were obtained from the implementation of a table from García's doctoral thesis, in which a methodological proposal is proposed for the elaboration of Environmental Declarations of Housing in Andalusia based on the mobility of users.
- A relationship was established between the life cycle stages considered and the design strategies defined, in order to identify the most appropriate construction system.

- End-of-life phase, including the deconstruction process (C1) and transport to the waste or recycling plant (C2), waste processing for reuse, recovery or/and recycling (C3) and final disposal (C4).

III. Selection of models: A case study was chosen, which is located in the Hipercentro del Norte de Quito, is within the radius of influence of the Eco-Efficiency Matrix, is a building for residential use, has the total number of constructed floors allowed according to current regulations and on which a light and fast-assembly architectural prototype was modeled.

IV. Functional unit: it considered in the study was the building system.

V. Limitations and assumptions: Real scenarios for the assembly and disassembly cycles were assumed of the building. For energy quantification during the construction and deconstruction phase, the proportions of the volume of building materials used as well as the diesel and electricity consumed were taken into account following the recommendations of Kellenberger (2004). Processes relating to health and safety measures during the construction processes (individual protection gear, perimeter security system, temporary fences) were ignored. The use stage phase was considered and the energy consumption during the operation of the building systems was included from the system boundaries.

VI. Evaluation tools: the emergence of the Eco-efficiency Matrix applied to multi-use buildings (commercial residential) was described.

VII. Description of the selected model: The existing construction was detailed and it was studied why the building is within the radius of influence of the Eco-efficiency Matrix.

VIII. BIM-ACV and GIS-ACV modeling: Through the use of BIM tools, the building was modeled with a Level of Definition (LOD) 300, to obtain quantification tables that were linked to the Life Cycle Analysis of the possible floors. allowed to be built and the environmental impact that this new building could cause with respect to its location and the housing densification of the intervention sector.

For the urban analysis, the GIS tool was implemented in order to obtain the distances of the different routes made by the users, depending on the location of the building in which they lived compared to the displacements they made in their daily lives.

The BIM-ACV and GIS-ACV tools were used separately because the first allowed the building scale analysis and the second urban scale. We have used the two tools to obtain different information, from the BIM model we have obtained all the information related to materiality and its quantification for inventory purposes and from the GIS model we have obtained distances at the city level.

IX. Interpretation of results: this article focused on knowing the impact of Global Warming (GWP), because in architecture it is the most relevant indicator of environmental pollution and is at the forefront of the global agenda due to its effects on world level. Also, this research was based on the interest in knowing if a city concentrated in height is more sustainable than a dispersed city; For this, the Eco-efficiency Matrix was used as an environmental evaluation tool introduced in recent years in the city of Quito.

Based on the use and analysis of this tool, a building was modeled to analyze it in the different ACV phases, with a special interest in knowing the environmental impact that is generated in the use phase, thus linking the movements of users depending on where the architectural model was implanted. For which, it was necessary to identify the busiest points of the Hypercenter of Quito, through the land use plan generated with the GIS software.

2.1 Case study description.

Quito, is the capital of Ecuador and it is located in Latin America. In 2018, for the first time it became the most populated city in Ecuador, with 2,735,987 inhabitants in total (INEC, 2019). In the second half of the 20th century, the city underwent a socio-economic and functional restructuring which contributed to the expansion of the population and with this a new longitudinal urban model (Instituto de la Ciudad de Quito, 2018). At present, the consolidated urban nucleus covers between 35 and 40 km on the longitudinal axis and between 5 and 8 km on the transversal axis (Instituto de la Ciudad de Quito, 2015) which makes Quito a dispersed city.

The two case studies are located in the sector of the Hypercentre of Quito, which receives many of the displacements generated, causing conflicts of mobility and pollution (Vallejo Subía, 2014). In this area has the highest concentration of buildings, with increasing numbers of floors due to the radius of influence of the Eco-Efficiency Matrix, that applies as it is located near the stops of the country's first underground metro line.

2.2 Assessment tools.

Cities are responsible for approximately 80% of global resource use and energy consumption as well as 75% of global greenhouse gas emissions (Lavers Westin, Kalmykova and Rosado, 2019). A reason for this happen, due partly to the continuous global change of cities where rural areas become urban. Thus, it is estimated that by 2050 68% of the world's population will be resident in cities, compared to 30% residing in cities in 1950. Therefore, in order to resolve the existing issues effectively it is essential to consider the environmental impact from a city (Lavers Westin, Kalmykova and Rosado, 2019).

In many cities, strategies and tools which contribute to the reduction of direct environmental impact, such as emissions to the atmosphere, are being implemented. However, they lack guidance for the reduction of indirect impacts which are the most complex to solve. (Lavers Westin, Kalmykova and Rosado, 2019).

The Eco-Efficiency Matrix tool has been in used in the city of Quito since 2016 to promote a compact city based on the concept of Transportation-Oriented Development (TOD). In other words, it promotes the densification of the city following the public transport axes of Fast Transit Buses (FTB) and the Quito Subway (Secretaría de Territorio, 2017).

For the application of the Eco-Efficiency Matrix has an instruction manual developed in Resolution 13-2016 by the Secretariat of Territory, Habitat and Housing of the Metropolitan District of Quito (STHV-DMQ) details the parameters and conditions required for projects to qualify for an increase in the number of floors. The percentage of growth in height (25%, 50%, 75% and 100%) is calculated based on the current number of floors assigned in the construction regulation report for each city lot (Table 1).

Number of current flats assigned in the regulation report	**Total points obtained in the matrix**							
	60 a 69 points (25% growth)		**70 a 79 points (50% growth)**		**80 a 89 points (75% growth)**		**80 a 89 points (100% growth)**	
	Number of additional floors	**Number Total Floors**	**Number of additional floors**	**Number Total Floors**	**Number of additional floors**	**Number Total Floors**	**Number of additional floors**	**Number Total Floors**
2	1	3	1	3	2	4	2	4
3	1	4	2	5	2	5	3	6
4	1	5	2	6	3	7	4	8
6	2	8	3	9	5	11	6	12
8	2	10	4	12	6	14	8	16
10	3	13	5	15	8	18	10	20
12	**3**	**15**	6	18	9	21	12	24
14	4	18	7	21	11	25	14	28
16	4	20	8	24	12	28	16	32
20	5	25	10	30	15	35	20	40

Table 1. Number of additional floors according to the percentage of Eco-Efficiency Achieved

The parameters that can be applied to achieve efficiency in water consumption are those of surface water retention and efficiency in drinking water consumption, grey water treatment and water reuse. To ensure efficient energy consumption, buildings must generate energy savings, promoting efficiency in energy consumption relating to mobility and housing densification. The use of eco-friendly materials, thermal and lighting comfort, proposal of gardens for public space and unification of lots is considered in order to obtain a score for the landscape, environmental and technological contributions.

2.3 Selection of models.

Some improvement parameters established in the Eco-Efficiency Matrix were applied to Model 1 to achieve a growth corresponding to 25% or three floors. This intervention was considered with lightweight materials to establish the impact of this building using impact values found in the EcoInvent database and associated with the BIM object to obtain the model LCA.

Model 1 corresponded to an existing building plus 25% growth. Terra Building is a housing project designed, planned and built by the Guerrero and Cornejo Arquitectos architects' studio. This building currently has 12 floors, as it is established in the regulations of the lot. Therefore, 25% would correspond to 3 floors, 50% to 6 floors, 75% to 9 floors, and 100% to 12 floors. In other words, if the highest score in the matrix was achieved, the Terra Building could have a total of 24 floors. As it is an existing building, only a growth of 25% was considered as a hypothesis so as not to affect the structure of the building. The parameters that were applied to the growth model, which is the same for both study cases were (Table 2):

Parameters	Considerations	Total points applying 100% of the parameters	Total Points Earned in 25%	
			MODEL 1 (Terra Building + building corresponding to 25% growth)	MODEL 2 (building corresponding to 25% growth)
Efficiency in water consumption	Percentage of Permeable Soil Area		2.50	2.50
	Percentage of retained rainwater		3.00	3.00
	Efficiency in drinking water consumption		5.00	5.00

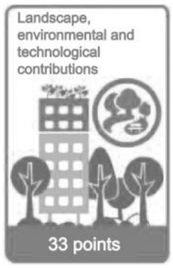
	Gray water treatment		3.50	3.50
	Reuse of rainwater		3.00	3.00
		SUBTOTAL POINTS	**17.00**	**17.00**
Efficiency in energy consumption	Energy saving		2.00	2.00
	Consumption/generation balance		0.00	0.00
	Spaces for shops, services and/or social facilities		2.00	2.00
	Diversity of uses		6.00	6.00
	Bicycle parking		2.00	2.00
	Reduction in the number of parking lots		6.00	6.00
	Population density (people/m2)		5.00	5.00
		SUBTOTAL POINTS	**23.00**	**23.00**
Landscape, environmental and technological contributions	Materials		3.00	3.00
	Use of lightweight materials in walls and slabs		4.00	4.00
	Rubble treatment		4.00	4.00
	Integration of the frontal retreat to the public space		5.00	5.00
	Batch unification		6.00	6.00
	Plant cover		1.50	1.50
	Reflectance and absorptance		1.00	1.00
	Thermal comfort		1.00	1.00
	Lighting comfort		1.50	1.50
		SUBTOTAL POINTS	**27.00**	**27.00**
		TOTAL POINTS FOR EACH MODEL	**67.00**	**67.00**

Table 2. Applied parameters of the eco-efficiency matrix for each model.

The two models for the development of this research were architecturally the same and followed the same BIM modelling (growth in height of 25% equal to 3 floors according to the Eco-Efficiency Matrix) so that the impact of the new model is exactly the same in the production, construction and recycling phases. The difference was observed in the phase of use of the model, which was conditioned by the trips made by users within the city. (Fig. 1, Fig. 2).

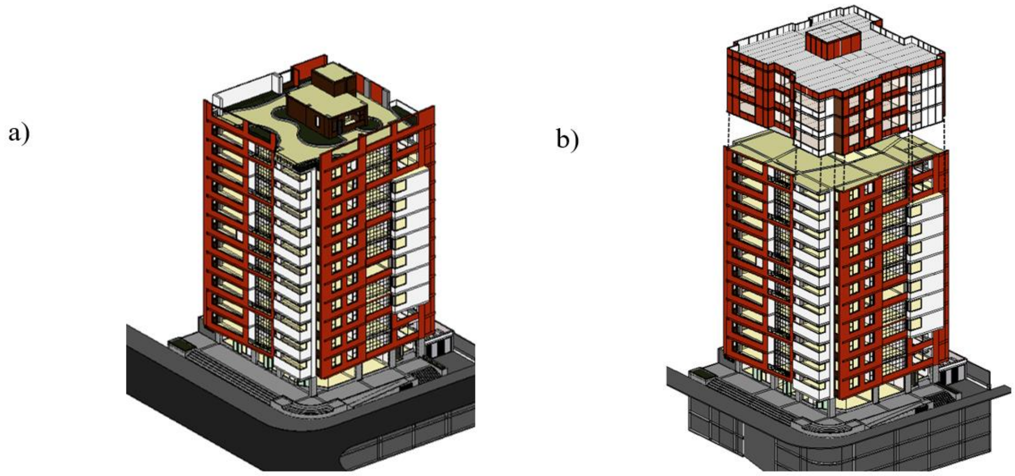


Fig. 1. Model 1: a) Present state of Terra Building b) Present state + 25% height increase (3 floors)

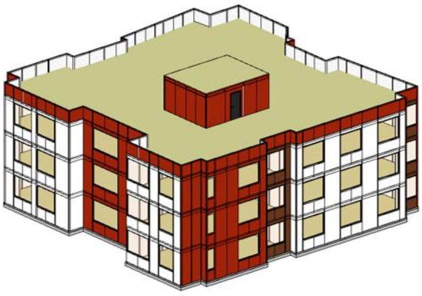


Fig. 2. Model 2 (25% height increase).

For the selection of the locations of the buildings, the following was considered: for model 1, the current location of the Terra Building was maintained, which is located near a subway stop, and for model 2, a site on the edge was sought. from the city's Hypercenter, specifically 4.5km from the first, in order not to be so far from the study area so that the analysis of the LCA use phase yields real data.

On a map of the city, the locations of the busiest places within the Hypercentre of Quito during the week and weekends were marked out in order to calculate the impact of transport, considering the number of trips to and from the models and to and from the points of interest in the sector studied. (Fig. 3).

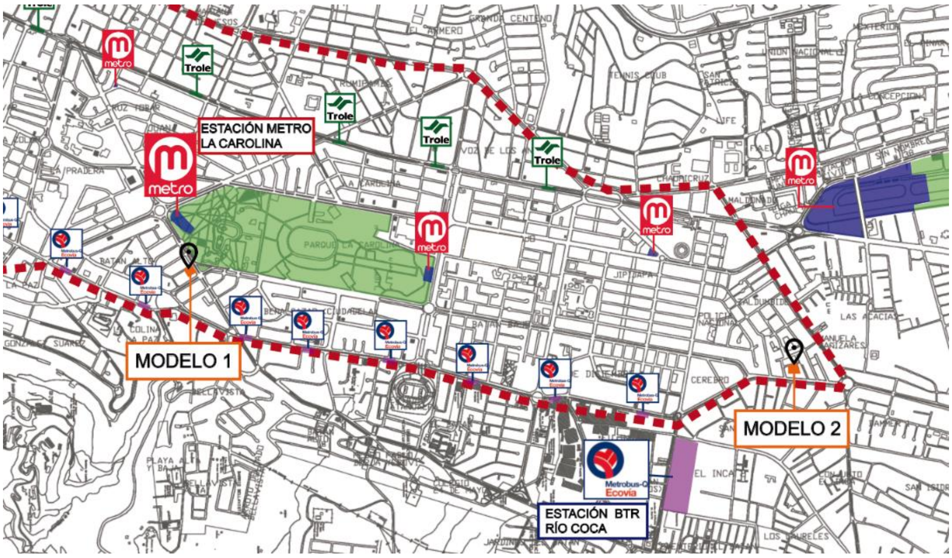


Fig. 3. Study Area (Northern Hypercentre of Quito). Model location.

The main reason for the increase in floors is for the Terra Building to densify and reach a greater number of people. Currently, on each floor of the 12 floors of the building there is a total of approximately 18 occupants/floor and by adding 54 additional users who would live in the 3 new increased floors, the housing density rose to 270 people for Model 1. While for Model 2, the 54 users remained. (Fig. 4).

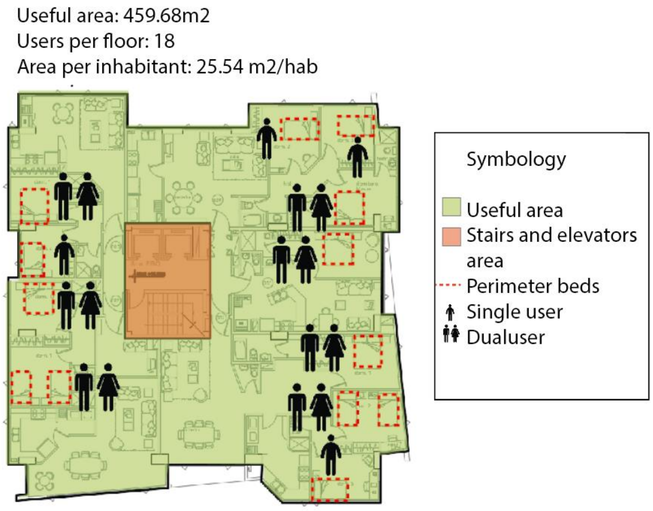


Fig. 4. Typical floor of the Terra building

The location for each model was considered to find out if the high-rise residential concentration near the Metro station (Model 1 case study) results in a lower impact on the use phase of the building compared to the displacement of users residing in the building. low-rise buildings (Model 2 case study) and that are far from the new Metro system.

2.4 GIS-LCA and BIM-LCA modelling.

The modelling was carried out using software BIM, with a level of development LOD 300. At this level, the early design stage is defined to make decisions, that is, the geometric definition is fully defined according to the final dimensions resulting from the calculation, the definition of the model elements is represented graphically in the model as systems, objects or assemblies with specific indications of size, shape, location and orientation.

The quantification tables obtained were linked to the LCA of the number of floors that could possibly be built and the potential environmental impact of these new buildings in relation to housing densification in the intervention sector. The analysis at urban level was carried out with the GIS tool.

After identifying the location of the 2 models, a GIS-type digital cartography was carried out to obtain geographical maps with data linked to the type of land use of the study area, the Quito Hypercentre, in order to establish the location of the largest amount of equipment.

After locating the points of interest at urban level, towards which most of the journeys converged, the distances to and from both models were calculated. On the route maps, all types of equipment were featured in a single colour so that their location could be visualized promptly. In situ monitoring recorded the trips made during the week or weekends. These trips were classified on foot, by car and by metro + FTB bus.

Each of these trips were represented in a layer of the GIS model, with what the number of kilometres travelled by users was easily obtained depending on their building of residence (Fig. 5, Fig. 6).

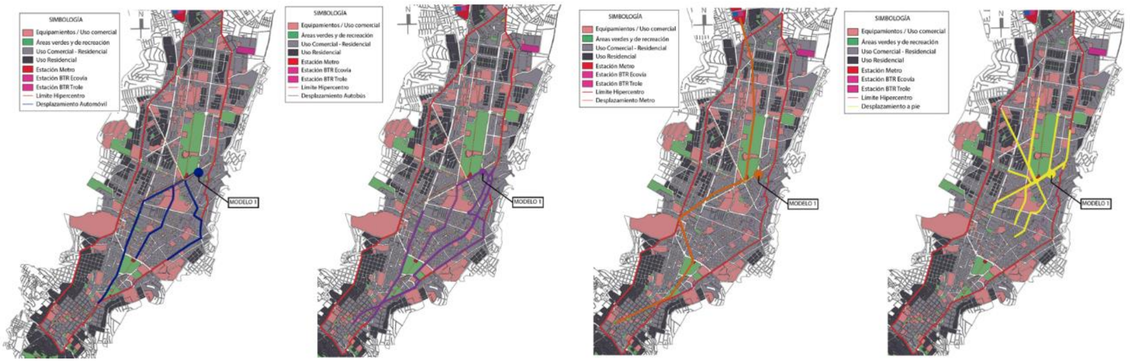


Fig. 5. Model 1 GIS map of travel routes by car, bus, subway and on foot.

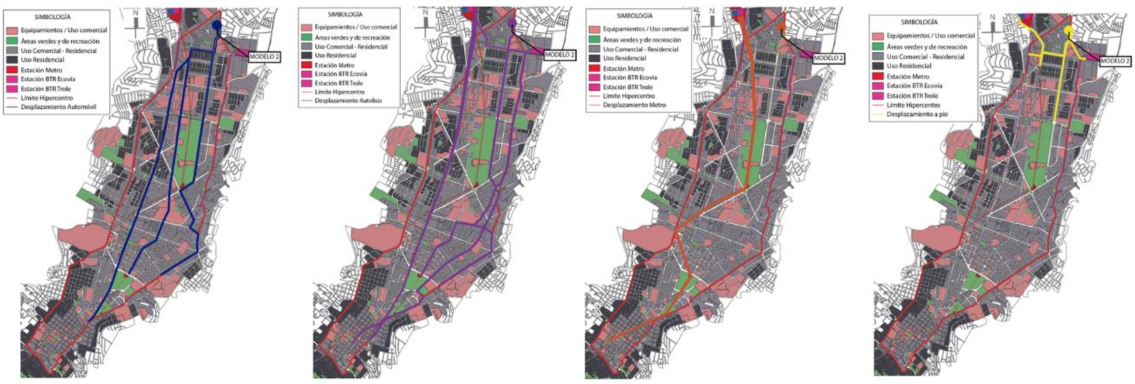


Fig. 6. Model 2 GIS map of travel routes by car, bus, subway and on foot.

The software used to carry out the GIS model was ArcGIS, which offers the following advantages (ArcGIS Resources, 2019):

- Creation, sharing and use of smart maps.
- Compilation of geographical information.
- Management and creation of geographical databases.

- Problem-solving with spatial analysis.
- Creation of map-based applications.
- Information sharing through geography and visualization.

The use of ArcGIS was considered for the purposes of this research, as it allowed the information on the type of land use of the Hypercentre to be linked more effectively, and the sectors with the greatest amount of equipment in the area of study to be visualized.

The existing scenario - the building in its current state - was not estimated for the LCA calculations. The materials corresponding to the 25% increase in height (3 floors) were simply considered and quantified. Although the building in its current state was not considered, it was necessary to carry out BIM modelling to understand the structural and architectural components of the case study.

The materials used for the BIM modelling of the case study with a 25% increase in height respond to a quick lightweight assembly system, different from that traditionally used in the construction of the existing scenario. It is important to mention that only the party walls between apartments were modelled, avoiding the inclusion of the interior walls of the different spaces. This is because this lightweight construction system enables a more flexible and diaphanous interior design which adapts to the new construction and modulation, although this was not the specific aim of this research (Table 3).

Family / Type	**Area (m^2)**	**Volume (m^3)**	**Density (kg/m^3)**
Rock wool insulation panel (Knauf TP 115 EPD 40 mm)	660.25	33.43	-
HPL panel	786.54	6.32	-
Gypsum panel	2,234.82	73.60	-
Foundation slab	501.63	125.41	-
Reinforced concrete slab, steel deck and reinforcing steel	1,451.09	159.62	-
Floor covering	1,952.72	29.29	-
Hot rolled steel sections RHS 200x80x4 mm	-	-	24,885.86
False ceiling with plasterboard panel	1,399.05	74.15	-
TOTAL	**8,986.1**	**501.82**	**24,885.86**

Table 3. Model 2 material quantification (25% increase).

Once the model was obtained and each of the components defined, the specifications and characteristics of the materials were entered into Tally, a Revit plugin used to calculate the different impacts of the materials in the LCA phases of both models.

2.5 LCA methodological options.

- Life Cycle Assessment Methods

The following provides a description of terms and methods associated with the use of Tally to conduct life cycle assessment for construction works and construction products. Tally methodology is consistent with LCA standards ISO 14040-14044, ISO 21930:2017, ISO 21931:2010, EN 15804:2012, and EN 15978:2011.

- Studied objects

The life cycle assessment (LCA) results reported represent an analysis of a single building, multiple buildings, or a comparative analysis of two or more building design options. The assessment may represent the complete architectural, structural, and finish systems of the building(s) or a subset of those systems. This may be used to compare the relative environmental impacts associated with building components or for comparative study with one or more reference buildings. Design options may represent a full or partial building across various stages of the design process, or they may represent multiple schemes of a full or partial building that are being compared to one another across a range of evaluation criteria.

- Functional unit and reference unit

A functional unit is the quantified performance of a product, building, or system that defines the object of the study. The functional unit of a single building should include the building type(e.g. office, factory), relevant technical and functional requirements(e.g. regulatory requirements, energy performance), pattern of use (e.g. occupancy, usable floor area), and the required service life. For a design option comparison of a partial building, the functional unit is the complete set of building systems or products that perform a given function. It is the responsibility of the modeler to assure that reference buildings or design options are functionally equivalent in terms of scope and relevant performance. The expected life of the building has a default value of 60 years and can be modified by the modeler.

The reference unit is the full collection of processes and materials required to produce a building or portion thereof and is quantified according to the given goal and scope of the assessment over the full life of the building. If construction impacts are included in the assessment, the reference unit also includes the energy, water, and fuel consumed on the building site during construction. Ifoperational energy is included in the assessment, the reference unit includes the electrical and thermal energy consumed on site over the life of the building.

- Data source

Tally utilizes a custom designed LCA database that combinesmaterial attributes, assembly details, and architectural specifications with environmental impact data resulting from the collaboration between KieranTimberlake and thinkstep. LCA modeling was conducted in GaBi 8.5 using GaBi 2018 databases and in accordance with GaBi databases and modeling principles. The data used are intended to represent the US and the year 2017. Where representative data were unavailable, proxy data were used.

The datasets used, their geographic region, and year of reference are listed for each entry. An effort was made to choose proxy datasets that are technologically consistent with the relevant entry.

- Data quality and uncertainty

Uncertainty in results can stem from both the data used and their application. Data quality is judged by: its measured, calculated, or estimated precision; its completeness, such as unreported emissions; its consistency, or degree of uniformity of the methodology applied on a study serving as a data source; and geographical, temporal, and technological representativeness. The GaBi LCI databases have been used in LCA models worldwide in both industrial and scientific applications. These LCI databases have additionally been used both as internal and critically reviewed and published studies. Uncertainty introduced by the use of proxy data is reduced by using technologically, geographically, and/or temporally similar data. It is the responsibility of the modeler to appropriately apply the predefined material entries to the building under study.

- System boundaries and delimitations

The analysis accounts for the full cradle to grave life cycle of the design options studied across all life cycle stages, including material manufacturing, maintenance and replacement, and eventual end of life. Optionally, the construction impacts and operational energy of the building can be included within the scope. Product stage

impacts are excluded for materials and components indicated as existing or salvaged by the modeler. The modeler defines whether the boundary includes or excludes the flow of biogenic carbon, which is the carbon absorbed and generated by biological sources

(e.g. trees, algae) rather than from fossil resources. Architectural materials and assemblies include all materials required for the product's manufacturing and use including hardware, sealants, adhesives, coatings, and finishing. The materials are included up to a 1% cut-off factor by mass except for known materials that have high environmental impacts at low levels. In these cases, a 1% cut-off was implemented by impact.

- Life Cycle Stages

The following describes the scope and system boudaries used to define each stage of the life cycle of a building or building product, from raw material acquisition to final disposal. For products listed in Tally as Environmental Product Declarations (EPD), the full life cycle impacts are included, even if the published EPD only includes the

- Product stage [A1-A3]. Product [EN 15978 A1 - A3]

This encompasses the full manufacturing stage, including raw material extraction and processing, intermediate transportation, and final manufacturing and assembly. The product stage scope is listed for each entry, detailing any specific inclusions or exclusions that falloutside of the cradle to gate scope. Infrastructure (buildings and machinery) required for the manufacturing and assembly of building materials are not included and are considered outside the scope of assessment.

- Transportation [EN 15978 A4]

This counts transportation from the manufacturer to the building site during the construction stage and can be modified by the modeler.

- Construction Installation [EN 15978 A5] (Optional)

This includes the anticipated or measured energy and water consumed on-site during the construction installation process, as specified by the modeler.

- Maintenance and Replacement [EN 15978 B2-B5]

This encompasses the replacement of materials in accordance with their expected service life. This includes the end of life treatment of the existing products as well as the cradle to gate manufacturing and transportation to site of the replacement products. The service life is specified separately for each product. Refurbishment of materials marked as existing or salvaged by the modeler is also included.

- Operational Energy [EN 15978 B6] (Optional)

This is based on the anticipated or measured energy and natural gas consumed at the building site over the lifetime of the building, as indicated by the modeler.

- End of Life [EN 15978 C2-C4]

This includes the relevant material collection rates for recycling, processing requirements for recycled materials, incineration rates, and landfilling rates. The impacts associated with landfilling are based on average material properties, such as plastic waste, biodegradable waste, or inert material. Stage C2 encompasses the transport from the construction site to end-of-life treatment based on national averages. Stages C3-C4 account for waste processing and disposal, i.e., impacts associated with landfilling or incineration.

- Module D [EN 15978 D]

This accounts for reuse potentials that fall beyond the system boundary, such as energy recovery and recycling of materials. Along with processing requirements, the recycling of materials is modelled using an avoided burden approach, where the burden of primary material production is allocated to the subsequent life cycle based on the quantity of recovered secondary material. Incineration of materials includes credit for average US energy recovery rates.

- Environmental Impact Categories

A characterization scheme translates all emissions and fuel use associated with the reference flow into quantities of categorized environmental impact. As the degree that the emissions will result in environmental harm depends on regional ecosystem conditions and the location in which they occur, the results are reported as impact potential. Potential impacts are reported in kilograms of equivalent relative contribution (eq) of an emission commonly associated with that form of environmental impact (e.g. kg CO_2 eq).

The following list provides a description of environmental impact categories reported according to the TRACI 2.1 characterization scheme, the environmental impact model developed by the US EPA to quantify environmental impact risk associated with emissions to the environment in the United States. TRACI is the standard environmental impact reporting format for LCA in North America.

Impacts associated with land use change and fresh water depletion are not included in TRACI 2.1. For more information on TRACI 2.1, reference Bare 2010, EPA 2012, and Guinée 2001. For further description of measurement of environmental impacts in LCA, see Simonen 2014.

- Global Warming Potential (GWP) kg CO_2 eq

A measure of greenhouse gas emissions, such as carbon dioxide and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may, in turn, have adverse impacts on ecosystem health, human health, and material welfare.

3. Results and discussion.

3.1 LCA at city level.

In order to quantify the impact generated by user travel (by bus, car, metro) in each of the models, the table "Urban and local displacements in housing" by Dr. Antonio García Martínez (2010), which was drawn up in the development of his Doctoral Thesis "Life Cycle Assessment (LCA) of Buildings, methodological proposal for the development of Environmental Declarations of Dwellings in Andalusia" was used as reference (García, 2010).

This table was linked to the tables of distances obtained from each of the displacements with ArcGIS. Thus, the results were more visual, real and representative as they were obtained with a tool which requires geographical information. In order to draw up the route maps, the points with the highest number of trips during the week and weekends were located as indicated in the following figures for models 1 and 2 (Fig. 7).

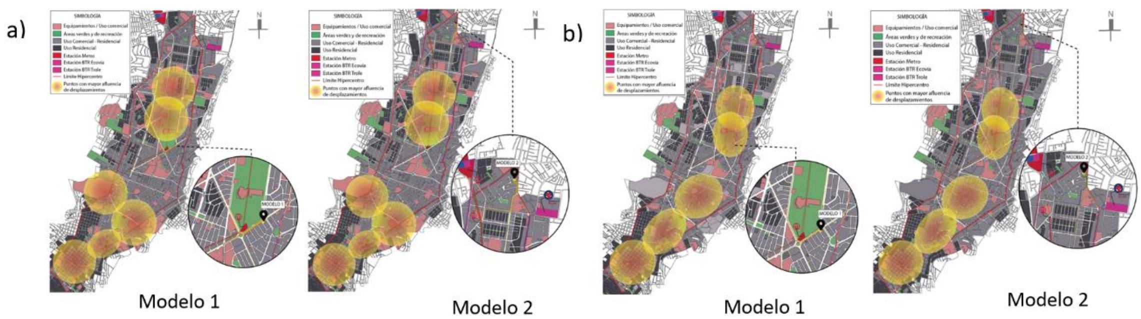


Fig. 7. GIS maps: a) Crowded places during the week b) Crowded places on the weekend.

The displacements obtained were quantified with the use of ArcGIS, identifying the routes and means of transport most used by the building occupants throughout the life cycle of the study model.

The occupation scenario during the useful life of the model is directly linked to the composition, size and family model of the dwelling's inhabitants (Table 4, Table 5).

Occupants depending on the number of bedrooms at home			
	Adult 1	**Adult 2**	**Children**
1 bedroom	1	0.5	0
2 bedrooms	1	0.85	0.4
3 bedrooms	1	0.85	1.4
4 bedrooms	1	0.85	2.8

Table 4. Number of occupants depending on the number of bedrooms at home. Source: PhD Thesis "Life Cycle Analysis (LCA) of Buildings. Methodological proposal for the development of Environmental Declarations of Dwellings in Andalusia". Dr. Antonio García Martínez (2010).

Average number of occupants throughout the life cycle	
	Occupants
1 bedroom	1.50
2 bedrooms	2.05
3 bedrooms	2.55
4 bedrooms	3.10

Table 5. Average number of occupants throughout the life cycle. Source: PhD Thesis "Life Cycle Analysis (LCA) of Buildings. Methodological proposal for the development of Environmental Declarations of Dwellings in Andalusia". Dr. Antonio García Martínez (2010).

The following parameters were calculated:

- Urban and local displacements: based on the distances, taking the location of the two models as the place of origin of the displacements towards the points with the greatest influx of users, showing the equipment required to satisfy the needs of the occupants (work, education, shopping, leisure, etc.). The urban and local displacements of the two models were calculated with the table developed in the doctoral thesis of García Martinez A. in which only the parameters n2, n6, n7 and n8 applied to the Quito hypercenter were entered. (Table 6, Table 7).

STARTING DATA				**WORK / EDUCATION / SHOPPING**						**LEISURE**						**TOTAL RESULTS**	
	Years	Weeks	Nº People	Distance (km)	Journey (km/day)	Mean of transport	Coefficient	Days /week	**Total Working**	Distance (km)	Journey (km/day)	Mean of transport	Coefficient	Days /week	**Total Leisure**	**Total per family**	**Total per building (x15 dwellings)**
H1	27	1,408.82	1.00	18.023	36.046	Car	0.5 ^{n2}	5	**126,955.94**	2.5 ^{n6}	5.00	Car	0.05 ^{n7}	2	**704.41**	**127,660.35**	**1,914,905.31**
				18.023	36.046	Bus	0.5 ^{n2}	5	**126,955.94**	2.5	5.00	Bus	0.1 ^{n8}	2	**1,408.82**	**128,364.76**	**1,925,471.47**
H2	9	469.61	1.00	4.25	8.50	On Foot	0	2	**0.00**	2.5	5.00	Car	0.05 ^{n7}	2	**234.80**	**234.80**	**3,522.05**
										2.5	5.00	Bus	0.1 ^{n8}	2	**469.61**	**469.61**	**7,044.11**
H3	15	782.68	1.00	4.25	8.50	Car	0.5 ^{n3}	1	**3,326.38**	2.5	5.00	Car	0.5 ^{n9}	1	**1,956.70**	**5,283.08**	**79,246.21**
M1	16	845.29	0.85	18.023	36.046	Car	0.5 ^{n2}	5	**64,747.53**	2.5	5.00	Car	0.05 ^{n7}	2	**359.25**	**65,106.78**	**976,601.71**
				18,023	36.046	Bus	0.5 ^{n2}	5	**64,747.53**	2.5	5.00	Bus	0.1 ^{n8}	2	**718.50**	**65,466.03**	**981,990.45**
M2	20	1,033.14	0.85	4.25	8.50	On Foot	0	2	**0.00**	2.5	5.00	Car	0.05 ^{n7}	2	**439.08**	**439.08**	**6,586.24**
										2.5	5.00	Bus	0.1 ^{n8}	2	**878.17**	**878.17**	**13,172.48**
M3	15	782.68	0.85	4.25	8.50	Car	0.5 ^{n3}	1	**2,827.43**	2.5	5.00	Car	0.5 ^{n9}	1	**1,663.19**	**4,490.62**	**67,359.27**
N1	3	156.54	1.40	4.25	8.50	Car	1	0 ^{n5}	**0.00**	2.5	5.00	Car	1	0	**0.00**	**0.00**	**0.00**

N2	10	521.79	1.40	4.25	8.50	On Foot	0	5	**0.00**	2.5	5.00	Car	0.0625 [n10]	1	**228.28**	**228.28**	**3,424.22**
										2.5	5.00	Bus	0.0625	1	**228.28**	**228.28**	**3,454.22**
N3	15	782.68	1.40	18.023 [n1]	36.046	Car	0.5	5	**98,743.51**	2.5	5.00	Car	0.25 [n11]	3	**4,109.06**	**102,852.57**	**1,542,788.61**
				18.023	36.046	Bus	0.5	5	**98,743.51**	2.5	5.00	Bus	0.25	3	**4,109.06**	**102,852.57**	**1,542,788.61**
															TOTAL DISPLACEMENT	**604,555.00**	**9,068,324.94**
															TOTAL DISPLACEMENT BY CAR (km)	**306,295.57**	**1,837,863.44**
															TOTAL DISPLACEMENT BY BUS (kmp)	**298,259.42**	**1,789,601.53**

NOTES

n1 It is assumed that 50% go to study/work by car and the other 50% by bus.
n2 In an area with a radius of 500 m made in the centre of Quito's Hypercentre, there are 16 bus stops, while in the surroundings of the plot (with the same radius) there are 8. In this way, the 16 stops are considered as 100% so 8 stops represent 50% of bus transport.
n3 The simultaneity coefficient is 0.5 since H3 and M3 are considered to move together.
n4 75% will use the car while the remaining 25% (corresponding to the first 3 years) will take the bus to commute.
n5 0 days/week are considered since the child will always go with one of their parents.
n6 2.5 km are considered towards the centre of the Hypercentre since the leisure in the surroundings would be done on foot.
n7 It is considered that 10% of people use the car. Since the leisure would be done as a couple, half of 10% is considered as a coefficient.
n8 It would be the other 10% that is considered to use the bus.
n9 The simultaneity coefficient is 0.5 since we consider that H3 and M3 would move at the same time.
n10 It is considered that in the last 3 years the transport conditions would change. It is equivalent to 25% of the total. Of this 25%, half would go on foot and the other half would go, in equal parts, by car and bus.
n11 It is considered that 50% of the time people will focus on leisure in the surroundings and the other 50% people will travel for this purpose (50% by car and 50% by bus).

Table 6. Urban and local displacements in housing Model 1. Source: PhD Thesis "Life Cycle Analysis (LCA) of Buildings. Methodological proposal for the development of Environmental Declarations of Dwellings in Andalusia". Dr. Antonio García Martínez (2010).

STARTING DATA				WORK / EDUCATION / SHOPPING						LEISURE						TOTAL RESULTS	
	Years	Weeks	Nº People	Distance (km)	Journey (km/day)	Mean of transport	Coefficient	Days /week	**Total Working**	Distance (km)	Journey (km/day)	Mean of transport	Coefficient	Days /week	**Total Leisure**	**Total per family**	**Total per building (x15 dwellings)**
H1	27	1,408.82	1.00	41.75	83.50	Car	0.63 [n2]	5	**370,555.26**	5.5 [n6]	11.00	Car	0.05 [n7]	2	**1,549.70**	**372,104.96**	**5,581,574.40**
				41.75	83.50	Bus	0.63 [n2]	5	**370,555.26**	5.5	11.00	Bus	0.1 [n8]	2	**3,099.41**	**373,654.66**	**5,604,819.95**
H2	9	469.61	1.00	4.275	8.55	On Foot	0	2	**0.00**	5.5	11.00	Car	0.05 [n7]	2	**516.57**	**516.57**	**7,748.52**
										5.5	11.00	Bus	0.1 [n8]	2	**1,033.14**	**1,033.14**	**15,497.04**
H3	15	782.68	1.00	4.275	8.55	Car	0.5 [n3]	1	**3,345.95**	5.5	11.00	Car	0.5 [n9]	1	**4,304.73**	**7,650.68**	**114,760.25**
M1	16	845.29	0.85	41.75	83.50	Car	0.63 [n2]	5	**188,983.18**	5.5	11.00	Car	0.05 [n7]	2	**790.35**	**189,773.53**	**2,846,602.94**
				41.75	83.50	Bus	0.63 [n2]	5	**188,983.18**	5.5	11.00	Bus	0.1 [n8]	2	**1,580.70**	**190,563.88**	**2,858,458.17**
M2	20	1,033.14	0.85	4.275	8.55	On Foot	0	2	**0.00**	5.5	11.00	Car	0.05 [n7]	2	**965.98**	**965.98**	**14,489.73**
										5.5	11.00	Bus	0.1 [n8]	2	**1,931,96**	**1,931.96**	**28,979.46**
M3	15	782.68	0.85	4.275	8.55	Car	0.5 [n3]	1	**2,844.06**	5.5	11.00	Car	0.5 [n9]	1	**3,659.02**	**6,503.08**	**97,546.21**
N1	3	156.54	1.40	4.275	8.55	Car	1	0 [n5]	**0.00**	5.5	11.00	Car	1	0	**0.00**	**0.00**	**0.00**
N2	10	521.79	1.40	4.275	8.55	On Foot	0	5	**0.00**	5.5	11.00	Car	0.0625 [n10]	1	**502.22**	**502.22**	**7,533.28**
										5.5	11.00	Bus	0.0625	1	**502.22**	**502.22**	**7,533.28**
N3	15	782.68	1.40	41.75 [n1]	83.50	Car	0.5	5	**288,737.81**	5.5	11.00	Car	0.25 [n11]	3	**9,039.94**	**237,777.75**	**3,566,666.25**
				41.75	83.50	Bus	0.5	5	**288,737.81**	5.5	11.00	Bus	0.25	3	**9,039.94**	**237,777.75**	**3,566,666.25**
															TOTAL DISPLACEMENT	**1,621,258.38**	**24,318,875.72**
															TOTAL DISPLACEMENT BY CAR (km)	**815,794.77**	**4,894,966.63**
															TOTAL DISPLACEMENT BY BUS (kmp)	**805,794.77**	**4,832,880.66**

NOTES

n1 It is assumed that 50% go to study/work by car and the other 50% by bus.
n2 In an area with a radius of 500 m made in the centre of Quito's Hypercentre, there are 16 bus stops, while in the surroundings of the plot (with the same radius) there are 8. In this way, the 16 stops are considered as 100% so 8 stops represent 50% of bus transport.
n3 The simultaneity coefficient is 0.5 since H3 and M3 are considered to move together.
n4 75% will use the car while the remaining 25% (corresponding to the first 3 years) will take the bus to commute.
n5 0 days/week are considered since the child will always go with one of their parents.
n6 2.5 km are considered towards the centre of the Hypercentre since the leisure in the surroundings would be done on foot.
n7 It is considered that 10% of people use the car. Since the leisure would be done as a couple, half of 10% is considered as a coefficient.
n8 It would be the other 10% that is considered to use the bus.
n9 The simultaneity coefficient is 0.5 since we consider that H3 and M3 would move at the same time.
n10 It is considered that in the last 3 years the transport conditions would change. It is equivalent to 25% of the total. Of this 25%, half would go on foot and the other half would go, in equal parts, by car and bus.
n11 It is considered that 50% of the time people will focus on leisure in the surroundings and the other 50% people will travel for this purpose (50% by car and 50% by bus).

Table 7. Urban and local displacements in housing Model 2. Source: PhD Thesis "Life Cycle Analysis (LCA) of Buildings. Methodological proposal for the development of Environmental Declarations of Dwellings in Andalusia". Dr. Antonio García Martínez (2010).

- Regional, national and international journeys: these journeys were quantified using estimated data applied to the population of Quito, as these parameters do not depend on case study location (Table 8).

	Unit	Calculation	Average journey per inhabitant in 50 years	Average journey per total building inhabitant in 50 years
Railway Transport				
Population of Quito 2018 (INEC)	p	2,735,987.00		
Journey (passenger-kilometres)	km	225.00		

Average journey per inhabitant / year	km	12,159.94	**607,997.11**	**1,550,392.63**
Air Transport				
Population of Quito 2018 (INEC)	p	2,735,987.00		
Number of passengers 2018 (estimation)	p	2,735,987.00		
Total Journey (passenger-kilometres) (estimation)	km	6,000.00		
Average journey per inhabitant / year	km	0.0022	**0.11**	**0.28**
Marine Transport				
Population of Quito 2018 (INEC)	p	2,735,987.00		
Number of passengers 2018 (estimation)	p	2,735,987.00		
Average journey per passenger (estimation)	km	2.95		
Total Journey (passenger-kilometres) (estimation)	km	8,071,161.65		
Average journey per inhabitant / year	km	0.34	**16.95**	**43.22**

Table 8. Average values of displacements of people at the regional, national and international level. Applies to Model 1 and 2. Source: PhD Thesis "Life Cycle Analysis (LCA) of Buildings. Methodological proposal for the development of Environmental Declarations of Dwellings in Andalusia". Dr. Antonio García Martínez (2010).

Once the necessary data were obtained to calculate the different impacts of the movements of the building's users throughout the life cycles for models 1 and 2, individual summary tables of the impact associated with the operational stage were made for each of these.

These required the input of the following data:

- Constructed area of the building: this value was calculated based on the Revit BIM model.
- Number of people in the building: 54 were considered, which corresponds to the largest number of users that a floor of the building has in its current state (a total of 18 people), multiplied by 3 floors corresponding to 25% increase in height.

The results obtained from the environmental impacts were (Table 9, Table 10):

- Total environmental impact of the building.
- Total environmental impact per dwelling.
- Total environmental impact per m^2 built.

- Total environmental impact per person.

MODEL 1						
Total dwelling's building area	1,504.89	m^2	Nº inhabitant / dwelling	2.55	Nº inhabitant	54.00
				SYSTEM 2		
ECOSUBCAT				OPERATION		
CML.2001	**Unit**	**Building**	**Dwelling**	**m^2/floor**	**Person**	**Total Impact building / person**
Climate change	kg CO2-Eq	3,373,542.98	224,902.87	149.45	88,197.20	4,164.87
Cumulative energy demand	**Unit**					
Biomass	MJ-Eq	7,123,014.38	474,867.63	315.55	186,222.60	8,793.84
Fossil	MJ-Eq	40,406,855.49	2,693,790.37	1,790.02	1,056,388.38	49,885.01
Nuclear	MJ-Eq	934,754.75	62,316.98	41.41	24,438.03	1,154.02
Water	MJ-Eq	934,754.75	62,316.98	41.41	24,438.03	1,154.02
Wind, solar, geothermal	MJ-Eq	503,114.11	33,540.94	22.29	13,153.31	621.13
Total embodied energy	***MJ-Eq***			***2,210.68***	**1,304,640.35**	**26,092.81**

Table 9. Summary of the impact associated with the operational stage of Model 1. Source: PhD Thesis "Life Cycle Analysis (LCA) of Buildings. Methodological proposal for the development of Environmental Declarations of Dwellings in Andalusia". Dr. Antonio García Martínez (2010).

MODEL 2						
Total dwelling's building area	1,504.89	m^2	Nº inhabitant / dwelling	2.55	Nº inhabitant	54.00
				SYSTEM 2		
ECOSUBCAT				OPERATION		
CML.2001	**Unit**	**Building**	**Dwelling**	**m^2/floor**	**Person**	**Total Impact building / person**
Climate change	kg CO2-Eq	6,288,369.70	419,224.65	278.57	164,401.82	7,763.42
Cumulative energy demand	**Unit**					
Biomass	MJ-Eq	7,154,647.67	476,976.51	316.95	187,049.61	8,832.90
Fossil	MJ-Eq	81,325,346.17	5,421,689.74	3,602.71	2,126,152.84	100,401.66
Nuclear	MJ-Eq	1,361,356.08	90,757.07	60.31	35,591.01	1,680.69
Water	MJ-Eq	1,361,356.08	90,757.07	60.31	35,591.01	1,680.69
Wind, solar, geothermal	MJ-Eq	527,167.49	35,144.50	23.35	13,782.16	650.82
Total embodied energy	***MJ-Eq***			***4,063.64***	**2,398,166.63**	**47,963.33**

Table 10. Summary of the impact associated with the operational stage of Model 2. Source: PhD Thesis "Life Cycle Analysis (LCA) of Buildings. Methodological proposal for the development of Environmental Declarations of Dwellings in Andalusia". Dr. Antonio García Martínez (2010).

3.2 Global Warming Potential - GWP

This paper focused on knowing the impact of Global Warming (GWP), because in architecture it is the most relevant indicator of environmental pollution and is at the forefront of the global agenda due to its effects worldwide, for this reason Global Warming Potential was considered as the main category for the analysis.

The graphs obtained from Tally for the various categories of environmental impact for Model 1 and for Model 2 showed very similar values.

The greatest amount of operational energy is generated mainly in the use phase when comparing the two models. In this phase both result in a greater environmental impact compared to the other phases of LCA (Table 11).

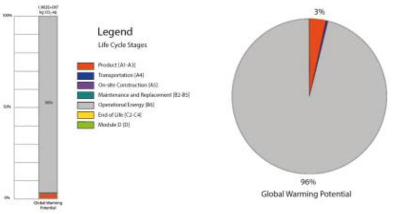
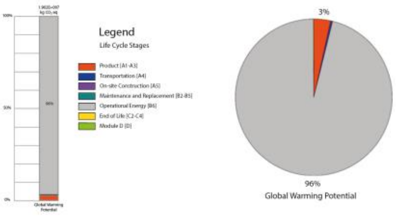
Enviromental Impact Totals	Product Stage [A1-A3]	Construction Stage [A4-A5]	Use Stage [B2-B6]	End of Life Stage [C2-C4]	
MODEL 1					
Global Warning (Kg CO2-Eq)	598,926	65,306	1.834E+007	11,157	
MODEL 2					
Global Warning (Kg CO2-Eq)	660,105	72,259	1.834E+007	16,834	

Table 11. GWP impact percentages with embodied energy according to LCA Stages - Model 1 and 2. Source: Tally Report.

As there was no notable difference between the results obtained in the GWP analysis produced by the models individually, it became necessary to link the movements made by users in order to identify the model with the greatest environmental impact in the use phase, which was the aim of this study.

The comparison of 2 models selected required the total LCA results obtained, based on the GWP impact for the architectural field (system 1) and urban field (system 2), and taking into account that all the GWP results have been expressed in kgCO2 eq.

Once the GWP impact values were obtained at urban level in tables 9 and 10, the GWP impact acquired for each BIM model was added, according to the results hosted by Tally. Thus, it was determined that Model 1 (building to which the Eco-Efficiency Matrix was applied due to proximity to the Metro station) produces the lowest GWP, 36.46% in total, compared to model 2, 4.5 km from the first case study, with an impact of 63.54%. In other words, the high-rise building with the greatest number of users produces the least GWP impact versus a low-rise building with lower housing density. The total results are expressed in the following tables (Table 12, Table 13 and Graph 8):

MODEL 1

System 1	Unit	Product Stage	Construction Stage	Use Stage	End of Life Stage	Total
Global Warning Potential	Kg CO2-Eq	598.926	65.306	917,000.00	11.157	917,675.39

System 2	Unit	Building	Dwelling	m^2/floor	Use Stage	Person	Total
Global Warning Potential	Kg CO2-Eq	3,373,542.98	224,902.87	149.45	917,000.00	88,197.20	4,603,792.50

Category	Unit	TOTAL System 1	TOTAL System 2	TOTAL
Global Warning Potential	Kg CO2-Eq	917,675.39	4,603,792.50	**5,521,467.89**

MODEL 2

System 1	Unit	Product Stage	Construction Stage	Use Stage	End of Life Stage	Total
Global Warning Potential	Kg CO2-Eq	660.105	72.259	917,000.00	16.834	917,749.20

System 2	Unit	Building	Dwelling	m^2/floor	Use Stage	Person	Total
Global Warning Potential	Kg CO2-Eq	6,288,369.70	419,224.65	278.57	917,000.00	164,401.82	8,706,274.74

Category	Unit	TOTAL System 1	TOTAL System 2	TOTAL
Global Warning Potential	Kg CO2-Eq	917,749.20	8,706,274.74	**9,624,023.94**

Table 12. GWP impact percentages with embodied energy according to LCA Stages - Model 1 and 2.

Model	Category	Unit	Total (model analyse) System 1	Total (commuting analyse) System 2	Total Impact
1	Global Warning Potential	Kg CO2-Eq	6.06 %	30.40 %	36.46 %
2	Global Warning Potential	Kg CO2-Eq	6.06 %	57.48 %	63.54 %
					100.00 %

Table 13. Total percentage of GWP impact for Model 1 and 2.

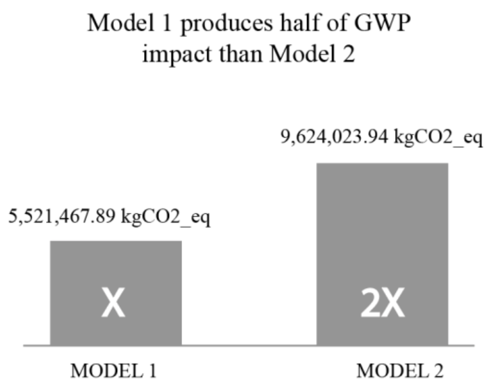


Fig.8. Comparative values of kgCO2e generated for model 1 and model 2.

It has been determined and verified that the impacts produced for the GWP category are specifically related to the displacements both in the construction and use phases of the building.

4. Conclusions.

After completing this study, the results establish that urban concentration in height reduces the environmental impact in the area of the Hypercentre of Quito, with Model 1 producing almost half the environmental impact (5,521,467.89 kgCO2_eq) of Model 2 (9,624,023.94 kgCO2_eq). That is, the users of model 2, who have to travel long distances to carry out their activities (work, study, shopping, leisure, etc.), have a greater impact on the city given that they use various means of transport to move around, unlike the users of Model 1, who can make more journeys on foot. (Fig. 8) In other words, model 1 with respect to model 2, supposes a reduction of the environmental impact of approximately 27%.

In the case of Quito, densification at height is much more sustainable than dispersion, as users do not have to make as many trips or use different means of transport, which allows the building's use phase to be reduced in terms of consumption and generation of operational energy, contributing to a more sustainable urban system.

A concentrated model driven by the implementation of the Eco-Efficiency Matrix based on TOD is a strategy that contributes to the reduction of the environmental impact of the area analysed, as shown in the comparative study, where the phase of use, including urban transport, is more likely to increase GWP, because it consumes more energy.

The GIS platform is a useful tool to determine the Life Cycle Inventory of urban systems. The main advantage of using this software was the ease for accurately quantifying the distances travelled by the users. Taking the location of the two models as the point of origin, the real geographical information of the study area was obtained, guaranteeing a more precise development of the investigation.

While LCA experiences at city level are not yet well developed, every effort was made to carry out a thorough review of the scientific literature to understand how LCA-GIS tools are being linked. In addition, the methodology used may be subject to continuous improvement, as new research is carried out, because this is the first master's thesis that covers this topic in the Master’s in Innovation in Architecture: Technology and Design of the University of Seville, Spain.

Thanks to the use of Revit software, it was possible to meet the objective of generating a BIM model, associated with the Tally plugin, through which the LCA of the two models was performed.

Finally, this research focused interest on one of the biggest environmental problems on a world scale: Global Warming, and it was essential to consider certain sustainability strategies being developed, such as the Eco-Efficiency Matrix in Quito. This strategy unquestionably invited us to think that it is possible to change the way construction archetypes are designed, which should be linked to the determination of the life cycle of urban systems.

Credit authorship contribution statement

Nelly Revello Cáceres: Conceptualization, Methodology, Investigation, Writing, Visualization. **Antonio García Martínez:** Conceptualization, Methodology, Validation, Resources, Writing, Supervision. **Juan Carlos Gómez de Cózar:** Conceptualization, Methodology, Validation, Writing, Supervision, Project Administration.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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