Structural Fire CO_2 Emission Models

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Abstract

The Costa Rican government set a goal to become carbon neutral by 2021. To achieve this goal, they must mitigate all CO_2 emissions. Each year there are 1,000 structural fires in Costa Rica that contribute to these emissions. Tracking the emissions from structural fires is a step towards achieving carbon neutrality. This project created two models in the form of a Java application to calculate emissions from fires in warehouses and industrial buildings. SHPI Ingeniería, our sponsor, will share the models with organizations to monitor and raise awareness about structural fire emissions. These organizations include Estado de la Nación, Carbono Neutral and the Bomberos. Future recommendations focus on creating an accurate model for hospital buildings.

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Executive Summary

Background

Greenhouse gases (GHGs) are the main cause of global warming. These air pollutants come from sources such as vehicles, factories, and fire emissions. In a global effort to reduce these harmful emissions, many countries have signed the Kyoto Protocol. The Kyoto Protocol is an international agreement that sets guidelines for countries to reduce their GHG emissions. Costa Rica took this a step further, and set the goal to become Carbon Neutral by the year 2021 in order to preserve its environment, as well as to prove to the world that such an ambitious goal can indeed be achieved. If successful, Costa Rica will be the first country to attain the carbon-neutral status, and several local companies have already taken the challenge to help their country advance in this effort.

In order for carbon neutrality to be achieved, Costa Rica must be able to track all of its CO_2 emissions, in order to mitigate them. The government has already created a strategy, Carbono Neutral, to achieve this goal. For Carbono Neutral to be effective, the initiative needs all the information it can get on CO_2 emissions.

Structural fires are a constantly overlooked source of carbon emissions. Fire reports normally disclose information on the casualties, damage, cost and cause of fire, but they rarely if ever report the emissions of materials that were burned. However, there are over 1,000 structural fires each year in Costa Rica, with an estimated emission of 34,000 metric tons of CO_2. Accurately tracking these emissions would help towards the end-goal of carbon mitigation.

This dearth of data on structural fire emissions is mostly due to the fact that research on tracking emissions from structural fires is in its infancy. There are currently international models in existence that track carbon emissions for a range of fires, including forest and residential fires. Costa Rica does not have such tools to track its fire emissions. Additionally, the international models that exist are focused primarily on residential buildings. There has not yet been extensive, published research for other types of structural fires, such as warehouse, industrial and hospital fires.

SHPI Ingeniería has taken it upon itself to create models that accurately track carbon emissions from residential, warehouse, industrial, and hospital building fires in Costa Rica. SHPI is a private fire protection company with a strong sense of social responsibility and environmental conscience. Creating structural fire emission models is part of their social responsibility. These models have two main purposes: to aid in the mitigation of carbon dioxide and to educate the public on the harmful effects of structural fires.

SHPI has worked previously with a WPI team, in 2014, in developing accurate structural fire emission models. The previous group that worked with them was able to complete the residential model of a Java Application that requires user input on several aspects of the residence to calculate the CO_2 emissions released if the building were to burn. They also started working on warehouse, industrial and hospital models. Our team was called upon to update and improve warehouse and industrial building models that were developed by the previous team, but that were not predicting accurate results.

The educational purpose of those models is as important as their contribution to the CO_2 mitigation and carbon neutrality. The Bomberos and the Estado de la Nación are organizations with annual publications where information like structural fire CO_2 emissions can be included. By using the results of the structural fire emission models, those two organizations will help in raising awareness of the harmful effects of fires to the environment, and give additional incentives for their prevention.

Objectives, Methods and Results

The goal of our project was to work with SHPI on updating two mathematical models to provide an estimate of carbon emissions from structural fires in Costa Rica. The two models were for warehouses and industrial buildings. In order to accomplish this goal, our project was organized around the following five objectives:

1. Understand the previous residential, industrial, warehouse and hospital models, their strengths and their limitations.
2. Refine the current models to improve the accuracy and reliability of their results.
3. Improve the user friendliness of the application.
4. Verify the improvement of the models by comparing them to already existing ones.
5. Provide SHPI with explanations on the functions of the current models and instructions on how they can update them in the future if needed.

Objective 1: Understand the previous residential, industrial, warehouse and hospital models, their strengths and their limitations.

In order to gain insight on the limitations of the previous models, we interviewed our sponsor and asked what specifically they would like to see improved in the new models. After interviewing our sponsor and conducting our own research, we gained valuable insight on why the previous industrial and warehouse models didn't work and what we could do to make them better. We also learned about the successful parts of the models.

While studying the formula used in the previous model, we understood that it included a variable known as an emission factor. An emission factor is the mass of CO_2 emitted per unit mass of material burned. Finding and calculating emission factors for various content materials was vital in improving the accuracy of the model, which was our second objective.

Understanding the successful residential model provided us with insight on how to approach the warehouse and industrial models. The residential model uses a *content vs. structure* approach which we adopted in our models. Also, the model calculates the emissions room by room. Both those divisions enable the user to input information in a logical sequence (first Room A, then Room B, etc). They also help the developer of the models organize the calculations. We used both the approaches in developing our own models.

Other important results from completing the first objectives were the limitations of the models we were called on to improve. Those were the limited user input of the Java application incorporating the models and the lack of specific averages for Costa Rican buildings used in the calculations. The first limitation is related to the amount of information input by the user and used to calculate an accurate estimate. To understand the second limitation, one must know that the models use averages for statistics such as insulation thickness in the walls and dimensions of shelves in warehouses. Those averages in the previous models were based on theoretical data rather than specific data to Costa Rican buildings, leading to inaccurate results. We used the findings from the first objective to formulate and achieve the following ones. We concluded that the two main areas of improvement were accuracy and user friendliness, which correspond to our second and third objective.

Objective 2: Refine the current models to improve the accuracy and reliability of their results.

After inspecting the previous models and noting their limitations, we decided to make the models more accurate by creating categories based on contents for each type of building (warehouse and industry). This was important since we found that different contents have a vast range of emission factors. Instead of having an average emission factor, we have more specific emission factors that correspond with each category. The categories were selected based on research of the most prevalent types of warehouses and industrial buildings.

To learn more about the building's structure, we conducted interviews with civil engineers that had a better understanding about how Costa Rican buildings are designed and the materials used. We asked them a series of questions to help us gain further insight about the structural materials of these buildings. From those interviews we learned that the most common materials used in construction were concrete, steel and polystyrene. We used those materials and their emission factors to calculate structure emissions in the warehouse and industrial models. In the application, a list with those materials is available for the user to select them as part of the building structure. Then the program uses the emission factor of the selected material to calculate its emissions.

Physical inspections were also part of our methods to examine contents and layouts of different buildings, as recommended by the previous group. Performing physical inspections to collect the missing specific data solved one of the limitations of the previous model, the lack of specific data to Costa Rican buildings. For these inspections, we created a worksheet. This worksheet was designed around emission factors, as they are essential to calculating carbon emissions.

Warehouse inspections gave us valuable information on the types of products stored in them. By using the worksheets, we kept track of all the products and created meaningful categories of materials. While inspecting commercial warehouses, we realized that we needed a means of user input that can put more than one category of products in a warehouse. For this reason, our model calculates content emissions by shelving unit. Having this specific shelving unit input increases the accuracy of the warehouse model.

We discovered that both warehouses and industrial buildings had many secondary rooms that needed to be taken into account in the calculations. This is something that was not noted by the previous group. In each building we inspected, we noted the content and dimensions of all secondary rooms found within. This information, along with the shelving units was used to accurately calculate the content emissions of warehouses.

During physical inspections of industrial buildings, we noticed many similarities to the warehouses. We took note of the raw materials, as well as the types of machinery and fuels used in each factory. We developed our categories based on data obtained from the CICR, which had a list of all registered industries in Costa Rica. We confirmed, through physical inspections and interviews that the structural materials used in industrial buildings were identical to the structural materials used in warehouses. We found that the types of secondary rooms were similar as well, along with the addition of control rooms. We discovered that the biggest potential source of carbon dioxide emissions came from the tanks of fuel used to provide energy to the industrial operations. For this reason, we allowed the user to input information about the fuel tanks by entering type of fuel and volume of the fuel tank. The other main source of emissions came from raw materials and finished goods storage. For raw materials, the user chooses the type of raw material as well as the mass of the material. If the user didn't know the mass, they can also input volume and density, which are then used to calculate mass. This same method was also used to calculate the emissions of finished goods. We chose not to include production machinery in our model calculations, due to the limited information available about the mass and types of materials the machines are made of.

The methods and results above lead to two accurate models, one for calculating emissions of warehouse fires and one for industrial fires. The models were developed in the form of a Java application. For this reason, our next objective was to improve the user friendliness of this application.

Objective 3: Improve the user friendliness of the application.

The application was designed to be easy to use, even without initial instructions, and to have a pleasantly simple interface. There are various features throughout the application designed to assist the user in entering accurate information. One such feature we added was default room loadings. These are average emissions per meter squared for different types of rooms. This is an option that allows the user to input accurate information into the application even when limited information is known about the room prior to its burning. A second feature we added to improve user friendliness was help boxes. These boxes are located throughout the app next to various user input fields. They are used to help the user understand what information the application is asking for, by providing images and descriptions pertaining to the specific user input field the help box is located next to. A third feature added to the application was input validation. This validation ensured that the format of the information the user input into the application matched the format of the information requested. To put it simply, if a number was requested, the application check to make sure that a number is input. If it is not, an error dialog will appear prompting the user to change their input.

In order to come to these decisions on user-friendly features, we first experimented with the previous models as end users. Once we created our own two models, we used those as well trying to break them and thinking as potential future users. However, we still needed feedback from first time users and for this reason we conducted a focus group.

The focus group consisted of SHPI personnel as well as members from the Bomberos. In the focus group we gave everyone the same imaginary scenario of a building burning down, and compared the numbers they got for total carbon emission. If they got results relatively close to one another, this means that the application was straightforward and easy to use. After they used the application, we had each member of the focus group fill out a feedback survey about user friendliness. The surveys gave us valuable feedback on the user friendliness and aesthetics of our application. We received fantastic ratings, with an 8.8 in aesthetics and an 8.2 in user friendliness. For everyone being a first time user, the only comment we received were to provide a brief tutorial in the beginning of using the application so that it would be easier to start. Overall, we were pleased with the outcome of the focus group because we plan to share the application with the Bomberos. Knowing that they used it with ease makes us confident that they will choose to use the models in the future to include their results in their annual reports.

Objective 4: Verify the improvement of the models by comparing them to already existing ones.

In order to verify our models, we compared them to the previous group's models and a working model used by the Environmental Protection Agency in the United States. This allowed us to prove that the application was performing the calculations correctly.

We compared our models to the previous group's models by entering the same information into each application. When comparing the results of the three models, the EPA model was too low to the total yearly emissions, the previous warehouse model was too high, and our model was the closest to the actual yearly emissions from structural fires. We therefore concluded that the result that our models give are realistic and more accurate than the previous model that we were trying to improve.

In order to prove that our application is performing the calculations correctly, we performed hand calculations for each step of the model. Then we compared those to the application result with the same input. There was an error of only 0.0002%, due only to the fact that the application rounds the end result to two decimal places, and our hand calculation were left at six. This result proved to us that the application was performing the correct calculations to find emissions of structural fires.

Objective 5: Provide SHPI with explanations on the functions of the current models and instructions on how they can update them in the future if needed.

We understand that our model is accurate for now, but with buildings codes constantly being updated and new construction materials being used, we needed to make sure the application can be modified if need be. Our two ways to accommodate are non-executable comments in the Java code as well as written instructions on updating the program. The code comments and instructions allow the editor to be able to make slight modifications to the application with no prior Java knowledge. The two main additions that are possible with our provided instructions are adding new materials and updating emission factors of already existing materials. We believe that with these additions, the model can remain up to date to the newest advancements of construction materials.

Recommendations

1. Continue updating the created warehouse and industrial models with additional materials based on the instructions accompanying these models.

The models we created are the first of their kind in Costa Rica. For this reason, as mentioned before, it is essential to keep them up to date.

2. Begin research into other environmentally harmful emissions from structural fires (CO, Particular Matter, VOCs etc.) and expand current models to include these emissions.

Carbon dioxide is not the only harmful greenhouse gas. Other gases released into the atmosphere need to be accounted for so the public is educated on their dangerous emissions in case of a structural fire.

3. Use the results of the application towards mitigating structural fire CO_2 emissions and achieving carbon neutrality.

We believe that the results of the models we created will be beneficial to Carbono Neutral for mitigating CO2 emissions from structural fires. For this reason, we urge SHPI to share the models and their results to the government branch so that they can use them towards the overall goal of carbon neutrality.

4. Implement a similar approach to create a Hospital Model with improved accuracy.

We did not have a sufficient amount of time to update the hospital model started by the previous group. Therefore, we recommend that future teams should come in and make a hospital model similar to the format of our other models. Then, the hospital model should be added to the application so that SHPI has a tool to track emissions from every type of structural fire in Costa Rica.

5. Add a category for power plants in the Industrial model.

Another sacrifice of our limited time was the absence of power plants from our industrial categories. Although power plants are few in number, those using fossil fuels and gases to produce electricity contain substances with very high emission factors. We expect that the emissions from a fire on such a power plant would have a great impact on the environment. We recommend that power plants be input into the model so the emissions from possible fires in this type of industrial buildings is able to be calculated.

Authorship

This report is the collaborative effort of Stella Banou, Devin Duarte, Kyle Fortin and Taylor Llodra. Each section has a primary author and a primary editor. However, all members made edits on the whole report. Kyle Fortin developed all the Java code for the application.

Table 1: Authorship Table

Section	**Author**
Title Page	S. Banou
Abstract	All
Acknowledgements	S. Banou
Executive Summary	All
Authorship	D. Duarte
Table of Contents	S. Banou
1. Introduction	All
2. Background	All
2.1. Costa Rican Carbon Neutrality	S. Banou, K. Fortin and T. Llodra
2.2. SHPI Ingeniería's Social Responsibility	S. Banou and K. Fortin
2.3. The Educational Purpose of Structure Fire Gas Emission Models	S. Banou and K. Fortin
2.4. The Bomberos	S. Banou and K. Fortin
2.5. The Programa Estado de la Nación	S. Banou and K. Fortin
2.6. SHPI and WPI's Collaboration to Create Structure Fire Gas Emission Models	S. Banou and K. Fortin
2.7. Existing Research on Fire Emissions	S. Banou and K. Fortin
3. Methodology	All
3.1. Objectives Outline	T. Llodra

3.2. Objective 1: Understanding the Complexity of Previous Models	T. Llodra and S. Banou
3.3. Objective 2: Refining the Models	T. Llodra
3.3.1. Warehouse Model	T. Llodra
3.3.2. Industrial Model	T. Llodra
3.3.3. Hospital Model	T. Llodra
3.4. Objective 3: Improving User Friendliness	T. Llodra
3.5. Objective 4: Verifying Improvement of the Models	T. Llodra
3.6. Objective 5: Provide SHPI with Methods to Improve Models	T. Llodra
3.7. Final Deliverable	T. Llodra
4. Data Collection and Model Development	S. Banou and K. Fortin
4.1. Emission Factors	S. Banou
4.2. Creating a Material Database	S. Banou
4.3. Increasing Accuracy of the Models	S. Banou and K. Fortin
4.3.1. Developing the Warehouse Model	S. Banou and K. Fortin
4.3.1.1. Calculating Emissions From the Warehouse Structure	S. Banou and K. Fortin
4.3.1.2. The Effect of Warehouse Layout on its Carbon Emissions	S. Banou and K. Fortin
4.3.1.3. Warehouse Content Emissions	S. Banou and K. Fortin
4.3.2. Developing the Industrial Model	S. Banou and K. Fortin
4.3.2.1. Industrial Building Structure Emissions	S. Banou and K. Fortin
4.3.2.2. Calculating Content Emissions for Factories	S. Banou and K. Fortin
4.4. Improving User Friendliness	S. Banou and K. Fortin
5. Model Evaluation	D. Duarte
5.1. Verifying Model Accuracy	D. Duarte and S. Banou
5.2. Feedback Session Results	D. Duarte
5.3. Creating Tutorials and Instructions	D. Duarte

6. Conclusions and Recommendations	T. Llodra, S. Banou and D. Duarte
6.1. Future Recommendations	T. Llodra
Bibliography	T. Llodra
Appendix A- Questions About Previous Models	All
Appendix B- Interview Questions for Civil Engineers	All
Appendix C- Data Sheet for Physical Inspections	K. Fortin
Appendix D- Feedback Session Survey	All
Appendix E- Sample of Material Database	D. Duarte
Appendix F- Warehouse Shelf Dimensions	All
Appendix G- Shelving Unit Mass Calculation	All
Appendix H- Shelving Unit Contents Calculation	K. Fortin
Appendix I- Default Room Loading for Bathroom	K. Fortin
Appendix J- Calculations for Gaging Model Accuracy	K. Fortin

Table of Contents

List of Figures

List of Tables

1. Introduction

Costa Rica is one of many countries affected by global warming. Its high biodiversity and dependence on ecotourism make the problem even more urgent, since global warming threatens the flora and fauna of the country (Climate change impacts in Costa Rica, n.d.) One of the main causes of global warming is the carbon dioxide trapped in the atmosphere, absorbing high energy levels and leading to rise in temperature. Due to the urgency of the problem in Costa Rica, the country set a goal to become carbon neutral by the year 2021 (President Aims for Carbon Neutrality, n.d.).

In order for a country to become carbon neutral, it must offset all of the carbon dioxide emitted into the atmosphere. Carbono Neutral is the strategy of the *Ministerio del Ambiente* in Costa Rica that works on achieving carbon neutrality through environmental projects. The first step in mitigating carbon emissions is to identify all of their sources. Then, the amount of carbon emitted must be monitored so it can be offset.

Different sources of carbon emissions include industrial operations, transportation, fires (structural and forest), energy production and domestic energy use. Our project focuses on the emissions of over 1,000 structural fires that occur annually in Costa Rica (Estadísticas: Investigación de Incendios, 2013). These fires contribute to the country's overall carbon emissions. The amount of carbon they emit is estimated to be equivalent to the annual emissions of 7,300 cars. As of now, there is no mechanism in Costa Rica available to accurately track the carbon emissions of structural fires. Such a mechanism would help the government of Costa Rica keep track of the carbon emissions from structural fires so that they can mitigate them.

Our sponsor, *Seguridad Humana y Protección contra Incendios Ingeniería,* or SHPI Ingeniería for short, took it upon themselves to create a mechanism to track carbon emissions from structural fires. This Central American engineering firm specializes in fire protection engineering and is devoting resources to locating the source of carbon emissions from structural fires, specifically in Costa Rica (SHPI Ingenieria, n.d.). SHPI Ingeniería's personnel believe it is their social responsibility to provide the Costa Rican government with information on the carbon emissions of structural fires. As a secondary goal, SHPI also plans to share the information with the education sector to raise awareness about structural fires and their environmental impact. SHPI realized that the only information that reaches the public through fire reports in Costa Rica is statistics on casualties and damages (Fire Sweeps through Calderon Guardia Hospital in Costa Rica, 2005). The environmental impact of fires is a topic not researched in Costa Rica so SHPI has made it one of their goals to be innovative on that matter. SHPI's educational endeavor is not part of their paid services; rather they feel it is their social obligation (Esteban Ramos, CEO).

SHPI Ingeniería has previously collaborated with students from Worcester Polytechnic Institute (WPI) to calculate carbon emissions from structural fires. Mathematical models were developed in 2014 by a WPI project team (Walker et al, 2014). These models take the form of a Java application into which users can input the specifics of the structure they are examining. The application then calculates the carbon dioxide emissions of the structural fire. The models calculate structural fire gas emissions for four different types of buildings: residential, warehouse, industrial and hospital.

The residential model developed in 2014 was proven accurate in comparison to pre-existing models in Scandinavian countries. SHPI determined that the warehouse, industrial and hospital models were inaccurate and required revision. These three models were based on theoretical research and case studies from Europe rather than physical inspections and data specific to Costa Rican buildings (Walker et al, 2014). The models do not account for varying types of building contents, and they use predetermined averages to roughly estimate the theoretical mass of combustible material in a structure. The previous WPI team recommended to the sponsor, SHPI, that the models be reworked to increase their accuracy. Our goal was to refine these three models to improve their accuracy at calculating CO_2 emissions from the aforementioned types of structural fires.

Our team created revised warehouse and industrial models by collecting specific information on these two types of buildings with a series of methods. Physical inspections, interviews and research on previous models were the main methods used to collect accurate information, specific to Costa Rican warehouses and industries. While creating the two updated models, we focused on improving both their accuracy and user friendliness. The two new models were integrated in the application with the successful residential model to provide SHPI with an accurate tool to calculate emissions from structural fires in residential buildings, warehouses and industries. The results of the three models are ready to be used by SHPI. SHPI plans to share the models and their results with the government sectors that will use them for carbon offsetting.

Our vision is that information from our models will help Costa Rica reach its goal of carbon neutrality by 2021. Updating the hospital model is our primary recommendation to have a complete tool that can help carbon mitigation. We also envision that our models will provide information to raise awareness about the effects of structural fires in the atmosphere.

2. Background

In this chapter we begin with a brief overview of Costa Rica's goal to be carbon neutral, and what steps have been taken to achieve it. We then explain how structural fires fit into the general goal of carbon neutrality, to justify why we are researching them for our project. We continue by introducing SHPI Ingeniería and their goals for developing models to estimate structural fire gas emissions. Additionally we present previous research published by experts in the field of tracking carbon dioxide emissions in order to investigate different approaches in calculating carbon emissions. Previous research includes the residential model developed in 2014 by the previous WPI group that worked with SHPI.

2.1 Costa Rican Carbon Neutrality

Costa Rica is one of the top 20 most bio diverse countries on earth, in terms of both species and density. The country's total area is only about 51,000 km^2. However, this small area is home to nearly half a million species, which represent 4% on the earth's expected biodiversity (Murillo, K. (n.d.)). Now, Costa Rica's biodiversity is now in danger, due to global warming. Global warming is caused by a rise in temperature leading to rising sea levels, amongst other issues. Costa Rica, a country whose coastlines expand along two oceans, is immediately affected by the outcome of global warming. The rising sea levels threaten the availability of drinking water on the coastal areas whereas the rise in temperature will result in many endangered species that rely on the coral reef for survival. Areas, such as the Punta Arenas coast, could lose as much as 500 meters of land to the rising water. This would be catastrophic for urban areas in the region (Climate change impacts in Costa Rica, n.d.). All of these predicted outcomes create a necessity for changes to be made.

The global nature of the problem initiated the creation of the Kyoto Protocol in 1992. The Protocol is an international agreement to reduce the greenhouse gas emissions (GHGs) that cause global warming (United Nations Framework Convention, 2014). Costa Rica ratified the Kyoto Protocol as an attempt to counteract the predicted outcomes of global warming.

The threat posed to Costa Rica by increasing temperature and sea levels called for a more drastic measure than simply reducing GHGs emissions. Former President of Costa Rica, Óscar Arias, announced on June 7, 2007 his goal to make the country carbon neutral by 2021 ("President Aims for Carbon Neutrality", n.d.). This means that Costa Rica will not only reduce CO_2, one of the GHGs, but plans to completely offset all emissions. Upon accomplishing this goal, Costa Rica will become the first nation to be carbon neutral. Such an accomplishment will be very impressive for a developing country.

Costa Rica reached an all time high of carbon dioxide emissions in 2007, which was 1.92 metric tons per capita, demonstrated in the graph below (figure 1).

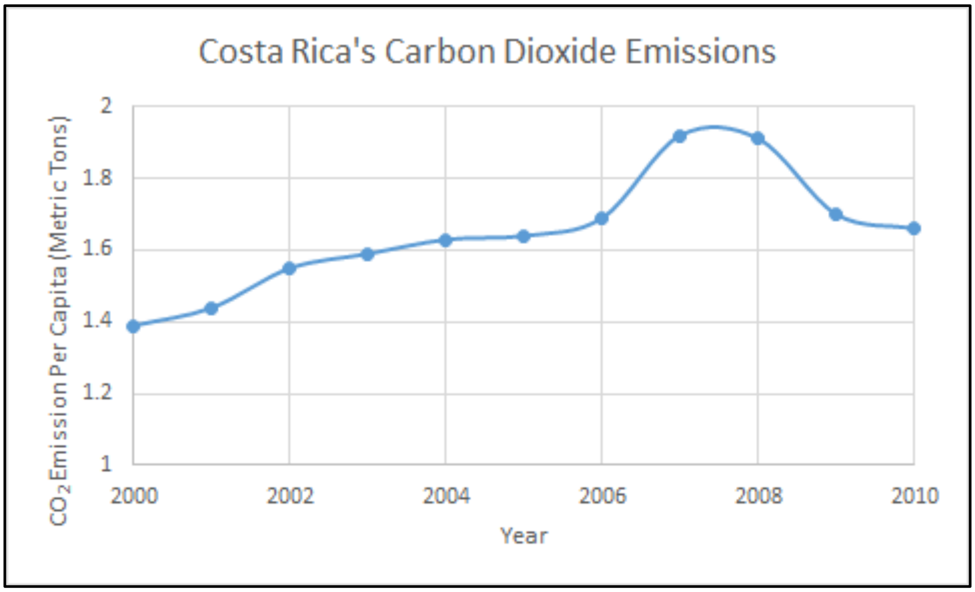

Figure 1: Costa Rica's Carbon Dioxide Emissions

Since their announcement in 2007 to become carbon neutral, Costa Ricans have continually reduced their emissions every year. In 2010 it was reported that the emissions were reduced to 1.66 metric tons per capita. As seen in the graph above, since the announcement in 2007 Costa Rica's per capita CO_2 emissions have decreased. These results are encouraging since they show Costa Rica's commitment towards carbon neutrality. In 2012, Costa Rica's CO_2 emissions were a mere 1.44 metric tons per capita in 2012, compared to 15.7 metric tons per capita in the U.S., it is on the right track (International Energy Statistics, 2013). The greatest accomplishment so far is the production of "94% of its electricity with zero carbon emissions, using mostly hydropower, some geothermal power and a very small amount from wind and biomass." ("President Aims for Carbon Neutrality", (n.d.)). By producing such a monumental percentage of its energy without emitting CO_2 to the atmosphere, Costa Rica can now focus on the offset of different sources of carbon dioxide to achieve carbon neutrality.

The government is actively pursuing carbon neutrality by creating a sector in the *Ministerio del Ambiente* called Carbono Neutral. This strategy is responsible for leading environmental projects that aim towards carbon offsetting. Some of the projects that Carbono Neutral is working on include reducing the need for fossil fuels as well as restoring the once obsolete public transportation system to a modernized world by adding hundreds of bus lines and railways linking the four major cities.

Entrepreneurs in Costa Rica share the government's goal of carbon neutrality. A vivid example of this is Dole Food Co. Inc.'s operating subsidiary in Costa Rica, Standard Fruit de Costa Rica. Leading by example, Dole has agreed to establish a carbon-neutral supply chain for their products (Dole, Costa Rica begin carbon-neutral, 2007). The company started tracking their carbon emissions from different segments of the production line. Figure 2 below shows the mass of CO_2 produced per kilogram of bananas produced in the Dole factory in Costa Rica ("Dole Sustainability", 2011).

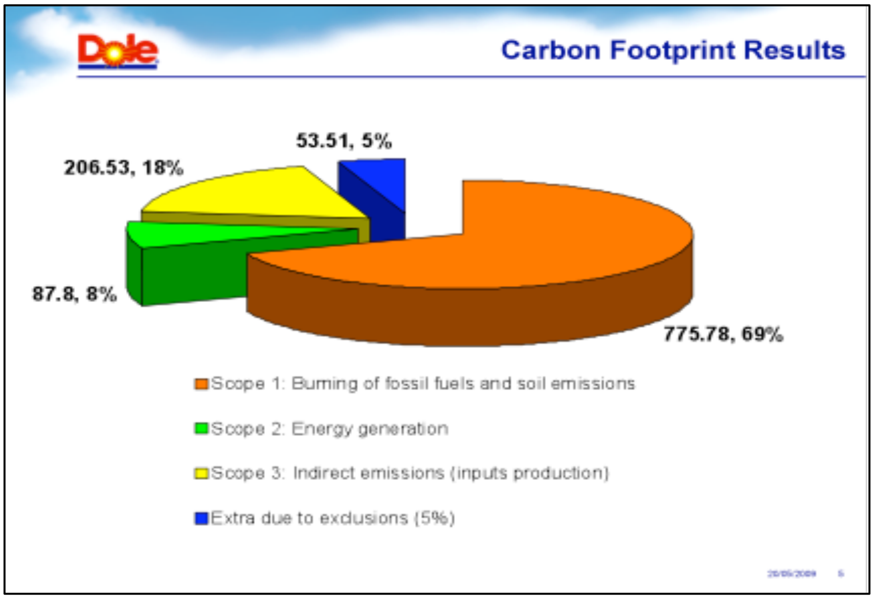

Figure 2: Dole Banana Production Carbon Footprint

They created and published figures like the one above, showing that they are deeply concerned with tracking their own CO_2 emissions and contributing to Costa Rica's overarching goal.

From Dole's strategy, we understand how important it is to track emissions in order to eradicate them. Since Dole is tracking their emissions and the sources of these emissions, they know the specific areas where they need to cut back on carbon use in order to become carbon neutral. Dole is not the only company that emphasizes corporate responsibility towards the environment. Fondo Nacional de Financiamiento Forestal (FONAFIFO), and Bridgestone Tire Company have already made efforts to become carbon neutral (Bridgestone, 2014). Other industries in the country are following suit. The fact that large corporations are getting involved in working towards this goal shows the country's commitment to achieving carbon neutrality by 2021.

2.2 SHPI Ingeniería's Social Responsibility

SHPI Ingeniería, our sponsor, is a new, small, private company that works to provide fire protection services in Costa Rica. Similar to the companies discussed in the previous section, SHPI has a social responsibility that is geared towards protection of the environment. SHPI values environmental safety ("SHPINGENIERIA S.A. :: ¿Quiénes Somos?"), and as part of their social responsibility towards the environment, they have collaborated with WPI to create mathematical models to track CO_2 emissions from structural fires. Creating the models is their own contribution to Costa Rica's overall goal of carbon neutrality.

SHPI Ingeniería understands that the carbon emissions from structural fires do not comprise the majority of the national footprint. However, carbon neutrality can only be achieved if every single source of CO_2 is mitigated. SHPI plans to share the results, and the models, with Carbono Neutral to provide them with a method to track this part of the nation's CO_2 emissions.

Another aspect of SHPI's social responsibility relates to educating the public on the harmful effects of structural fires on the environment. As Esteban Ramos, SHPI's CEO, has stated "people in Costa Rica hear about structural fires and only think as far as the damage on human lives and material possessions". There is a side of structural fires that has not been broached yet in Costa Rica; their environmental impact. SHPI's mission is to use the results of the models to raise social awareness and as an incentive for the prevention of structural fires.

When it comes to fire prevention, there are measures for preventing casualties, such as building design, evacuation plans and more. Also, there are measures for prevention of building damage with sprinklers and labels of flammable materials. Having a measurement of the environmental effect of structural fires will act as an incentive to increase fire prevention since, additionally to saving lives and preventing damage, preventing structural fires will reduce harmful emissions to the environment.

2.3 The Educational Purpose of Structure Fire Gas Emission Models

Education of the public on CO_2 emissions from structural fires is a major part of SHPI's mission. The way to achieve this mission is by collaborating with the Bomberos and the Estado de la Nación to share the information from the models with the public. The long-term plan is that all citizens of Costa Rica will know about the air pollution generated from structural fire emissions and this will act as an additional preventative measure.

2.3.1 The Bomberos

The *Benemerito Cuerpo de Bomberos* is the firefighting force of Costa Rica. For the Bomberos, having models that estimate CO_2 emissions of structural fires has two educational purposes. The results of structural fire emission models will benefit the firefighters themselves and will also become part of their annual reports to educate the public. Knowing the amount of CO_2 emitted in structural fires is useful to the Bomberos in educating their own force about the health hazards of carbon dioxide emissions. They fight to prevent fires from spreading and destroying property as well as threatening human lives. With fire being the immediate danger, not many people are aware of how carbon dioxide emissions threaten us. The firefighters are amongst the first people that come in close contact with structural fires. They experience first hand the harmful effects of CO_2. At higher concentrations, CO_2 leads to an increased respiratory rate, tachycardia, cardiac arrhythmias and impaired consciousness. Concentrations greater than 10% may cause convulsions, coma and death (Langford, "Carbon Dioxide Poisoning"). Based on the residential model developed by SHPI Ingeniería and WPI in 2014, an average residential fire in Costa Rica emits 27.78 metric tons of CO_2. This amount of carbon dioxide in the atmosphere can have a very serious, sometimes deadly impact to nearby people very quickly. Therefore, knowing the amount of CO_2 in the atmosphere around the fire they are putting out will help them prevent health problems by assessing the risks related to CO_2 poisoning.

Besides the health hazards of CO_2 emissions, the Bomberos force is interested in statistics of structural fires to enrich their yearly reports. During a visit to a station of the Bomberos, two members of the force (who prefered to stay anonymous) stated that the Bomberos would potentially benefit from this type of information in their report because they want the society to understand that there is a huge impact of structural fires on the environment that most people are unaware of. They share SHPI's goal to raise awareness of the environmental impact of fire emissions.

The Bomberos release statistics every year with the different types of fires that occurred, their sources and their impacts. In 2013, there were 1077 total structural fires in Costa Rica, 214 of which were investigated by the Bomberos ("Investigación de Incendios" 2013). Figure 3 below shows the breakdown of the investigated structural fires, by type of building. The information displayed in the figure is part of a longer report available on the web to the public.

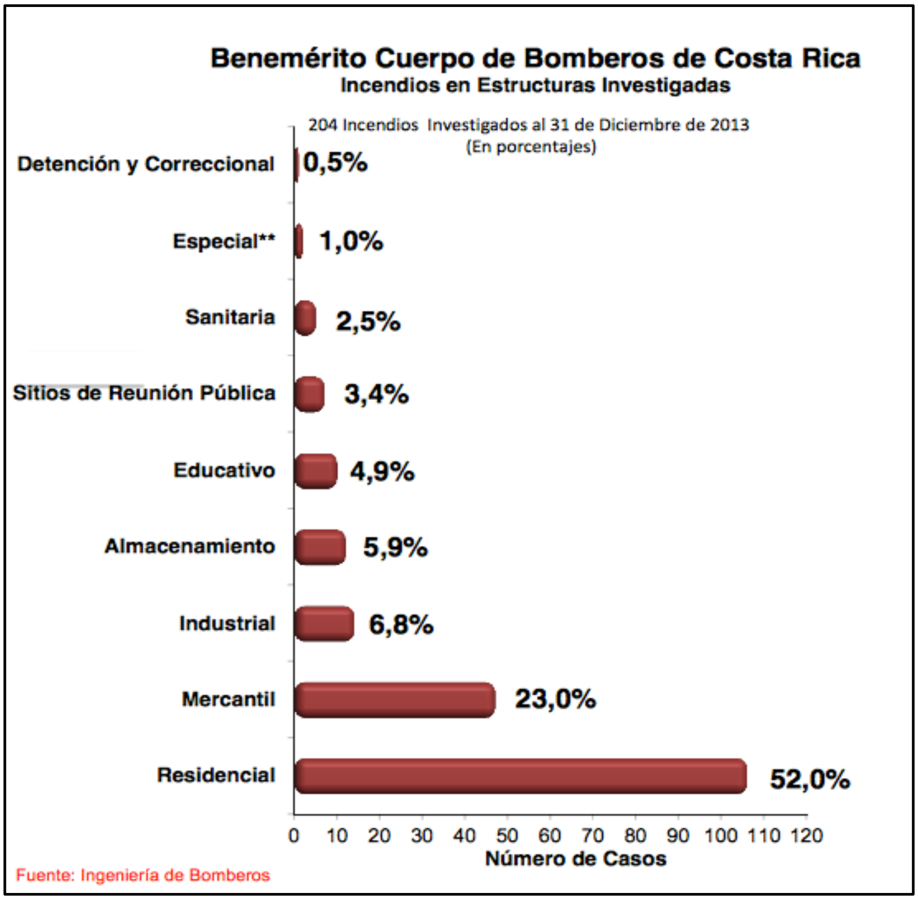

Figure 3: Breakdown of Structural Fires in Costa Rica in 2013

When SHPI shares the mathematical models with the Bomberos, they will be able to use the results to include them in their annual reports. The addition of the emissions of each incident would make the reports complete with information about the environmental impact of fires as well as their damage and cause.

2.3.2 The Programa Estado de la Nación

The Estado de la Nación program is a collaboration between the four public universities in Costa Rica. The program uses resources from the four universities to create educational modules in forms of annual printed journals called *Informes*. The mission statement of the Estado de la Nación states that the program aims to provide mechanisms to society wherein citizens may gain knowledge on their own development and evolution ("Quiénes somos?", 2015). The topics of the educational modules are environmental sustainability, social equality, economic stability, enforcement of the democracy and information on the elections (XIX Informe, 2013). They distribute the *Informes* to educational institutions and publish them on the web with free access.

Within the environmental sustainability chapter of each *Informe*, there is information about harmful environmental impacts of human intervention to nature.

Examples from previous modules include preservation of marine life, water quality, deforestation, urban development and air pollution. The topic of global warming and carbon dioxide emissions is recurring the past few years in the *Informes*. However, SHPI has been following the *Informes* for the past 5 years and has not yet encountered information about structural fire CO_2 emissions. The figure below is an example from the 2012 *Informe* section on carbon footprint.

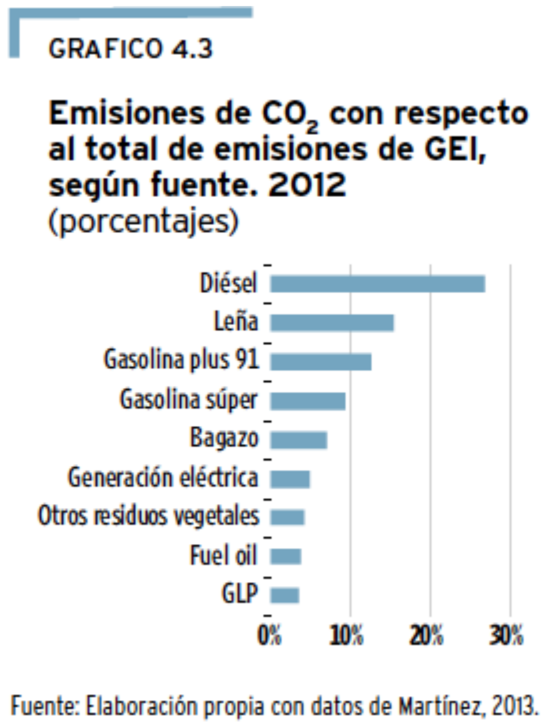

Figure 4 Carbon Dioxide Emissions in Costa Rica per Source in 2012

The figure shows what percentage of the overall GEI sources (Gases de Infecto Invernadero - Greenhouse Gases) emissions is CO_2. The sources listed are diesel, firewood, electricity generation, and more oils. As one can see, fire emissions are not listed as part of the GHG sources. The lack of mention of fires as sources of CO_2 is visible in all the *Informes*.

The results of the structural fire gas emission models will be provided by SHPI to the Estado de la Nación to become a part of the educational modules they provide. The results of the structure fire gas emission models can be used as part of modules on carbon neutrality, carbon footprint or any other topic related to air pollution.

2.4 SHPI and WPI's Collaboration to Create Structure Fire gas emission models

Our project was not the first attempt of SHPI to create mathematical models to estimate structural fire emissions. This project is a continuation of last year's IQP project titled "Structure Fire Gas Emissions". The group that went to Costa Rica in March 2014 created five models to estimate carbon dioxide (CO_2) emissions from structural fires. Four of these models were designed to calculate the emissions from specific categories of structures. These categories were industrial complexes, residential buildings, hospitals, and warehouses. The fifth model was an aggregate model, developed to determine the total combined CO_2 emissions from all structural fires (Hardin et al, 2014). The goal of our team's project is to evaluate and improve three out of five models created by the previous year's team. The three models predict CO_2 emissions from structural fires in warehouses, industrial buildings, and hospitals.

The aggregate model and the residential model are currently satisfactory and perform their intended function. The models were incorporated to a computer application. The application prompts the user to input information on the burnt structure and calculates the amount of CO_2 emitted from the fire based on the input. The user inputs the area of the structure, the burned area of the structure, as well as the primary structural and content materials. The application then provides an emissions estimate for the given structure, including all of the items found within. In figure 3 below, one can see that in the specific example, there was a partial fire. Only 70 m^2 out of 150 were affected by the fire.

Figure 5: Residential Application Screenshot

Creating fire emission estimation models is a research area that has been developed by before globally. SHPI's innovation is creating models specific for Costa Rica. The next section presents further research on the topic in an international scale.

2.5 Existing Research on Fire Emissions

Existing research on fire emissions dates back to only the beginning of the 21st century. This relatively new research topic has lead to the development of models for forest fires and mostly residential structural fires. Creating models for warehouses, industrial buildings and hospitals has not been part of the existing research on fire emissions. In this section we present the existing research on forest and structural fires.

Christine Wiedinmyer and her team at UC Boulder have created a method that uses satellite data and mathematical formulas to predict the amount of carbon dioxide emitted during fires in North America (Wiedinmyer, 2006). In their model, the emissions of carbon dioxide are the product of the area burned, the fuel loading factor, the combustion efficiency and the emission factor of said substance. The fuel-loading factor is the mass of fuel available to be burned per unit area. Combustion efficiency is the measurement of how well the fuel burned is combusted (turned into carbon). The emission factor is a number specific to each material that shows the amount of pollutant—in this case carbon dioxide—that is emitted during the combustion of this material per unit mass of the material. According to this model, each year in Costa Rica 1.17 million metric tons of carbon dioxide are emitted from fires (Wiedinmyer et al, 2006). Though Wiedinmyer's model is mostly applicable to large-scale forest fires, it can also serve as a good reference for other types of fires.

The Environmental Protection Agency (EPA) in the U.S. provides guidelines on the preferred methods to estimate emissions. EPA's preferred model was developed by California Air Resource Board (CARB). The model uses a series of averages of emission factors and fuel loading to calculate carbon dioxide emissions for a generic building, without specifying its use. These guidelines follow a model for structural fires wherein emissions are the product of emission factor, activity, the number of fires within the inventory area, and fuel loading (Preferred Method for Estimating Emissions, 2001). Fuel loadings for different types of rooms are found in L. Razdolsky's study Structural Fire Loads. Table 5.1 lists the fire loads of hospital rooms, hotel rooms, dwellings and offices.

The next model we looked at was developed by the SP Technical Research Institute in Sweden. The report on the model investigates fires in dwellings, schools and cars in the Nordic countries (Sweden, Norway, Finland, Denmark). The models were developed to compare the carbon dioxide emissions of fires among countries (Blomquist et al, n.d.). The report investigates fires in dwellings, schools and cars in the Nordic countries (Sweden, Norway, Finland, Denmark). The report aims to compare the carbon dioxide emissions of fires among countries (Blomquist et al, n.d.).

By contacting several organizations in different countries we investigated the existence of structural fire emissions models for warehouses, industrial buildings and hospitals. One of the organizations that shared information with us was the New Zealand

Fire Service. This organization funded a project that was to track the average emissions from residential fires. The independent research company BRANZ developed the "House Fire GHG Emissions Estimation Tool" project. However, when asked why warehouse or industrial building fires emissions are not investigated, Dick Thornton-Grimes, National Advisor of Hazardous Substances, stated: "The New Zealand Fire Service does not track greenhouse gas emissions of such fires and is unlikely to do so in the near future ". Along with the other companies we contacted we have yet to come across a country that uses a model to track carbon dioxide emissions for warehouse and industrial fires. The concept of tracking emissions from structural fires is new and has not yet been completely developed. Our models are innovative for calculating with accuracy the emissions from fires in warehouses and industrial buildings.

2.6 Background Conclusion

Research on our sponsor and their mission gave us a good understanding on the purpose of our models, once it is completed. Knowing the purpose was, of course, important for our own understanding of the models and their missions but did not become part of our methodology and results. The reason behind that is because our project was defined within very specific parameters. Our task focused on the technical development of the models and not its social purpose.

Researching already existing models helped us understand the uniqueness of the deliverable of this project. There has been development of models that calculate emissions of forest fires and structural fires in residential building but no information on warehouse or industrial fire emissions is public. The result of this project, the new warehouse and industrial models, will be the first of their kind in Costa Rica and very innovative globally.

3. Methodology

Our task was to update the warehouse, industrial, and hospital model versions of the app developed by the previous WPI group. The high level of detail, user interface and accuracy of the residential model must be consistent across all versions of the CO_2 emissions calculator application. Our project objectives were centered around improving the accuracy and user friendliness of the previous models by first obtaining a clear understanding of the residential model. After defining those objectives, we created our methodology to achieve them the best way possible.

3.1 Objectives Outline

The following objectives outline our project:

Objective 1: Understand the previous residential, industrial, warehouse and hospital models, their strengths and their limitations.

Objective 2: Refine the current models to improve the accuracy and reliability of their results.

Objective 3: Improve user friendliness of the application.

Objective 4: Verify the improvement of the models by comparing them to the already existing ones.

Objective 5: Provide SHPI with explanations on the functions of the current models and instructions on how they can update them in the future if needed.

3.2 Objective 1: Understanding the Complexity of Previous Models

The first step in refining someone else's work is understanding its limitations. In our case, we needed to understand why the previous warehouse, industrial and hospital models were not satisfactory. Additionally, we became experts on the variables used in the calculations of CO_2 emissions. Our methodology in order to achieve our first objective consisted of three main actions:

A. Interviewing the sponsor about last year's models

B. Reading and understanding the recommendations found in last year's report

C. Understanding the mathematical formulas and the variables used to calculate CO_2 emissions.

In our interview with Esteban Ramos, SHPI Ingeniería CEO, we asked a series of questions to understand why the previous industrial, warehouse and hospital models did not satisfy the needs of the company. The questions can be found in Appendix A. We asked questions about the success of the residential model as well as the limitations of the warehouse, industrial and hospital models. From this informal interview we wanted to compare the features of each model to see what parts of the successful residential model can be used to improve the warehouse, industrial and hospital models. Also, we needed an explanation of why the three previous models were described as inaccurate.

The result of this interview was that the inaccuracy of the three models was due to a lack of Costa-Rica-specific data on warehouses, industrial buildings and hospitals. The previous group specifies that they used theoretical studies from other countries to obtain the contents of buildings instead of physical inspections. In order to correct this, the previous group recommended that we revisit the three models and perform physical inspections to obtain accurate fuel loadings of buildings specific to Costa Rica. From comparing the three models with the residential model, we also concluded that approaching carbon emissions room by room was successful in the residential model. For this reason, we decided to adapt it for the industrial, warehouse and hospital models as well.

In addition to understanding the limitations of the previous models, we thoroughly read and understood the calculations made to obtain the gas emissions of structural fires in the residential model. As we learned from our extensive research about carbon emissions both before coming to Costa Rica as well as on the project site, there are numerous factors that must be taken into consideration to calculate CO_2 emissions from fires (emission factors, mass of burned material, area of fire, materials burned etc). All those factors can be manipulated in many different ways using numerous formulas to obtain a result. In section 2.5 of the Background chapter, we explain some of the already existing models for calculating CO_2 emissions. After studying the formulas that those models use and the formula that the group last year used for the residential model, we decided to use the latter. The residential model calculates CO_2 emissions by multiplying the amount of material burned and the emission factor. We decided to use this formula because it combines user input and literature values to obtain a result. Since we were designing an application, it was essential to use information input by the user (mass of material burnt, area affected) to make the result accurate and specific to each incident. By using the emission factor for each material as part of our calculation, we made sure that the result would be based on well-documented numbers from years of research on CO_2 emissions.

3.3 Objective 2: Refining the Models

By reviewing the issues of the past models we came up with several methods on how to make the models more accurate. The steps we chose to refine these models were the following:

A. Create categories for industrial, warehouse and hospital models.

B. Interview civil engineers to gain a better understanding of materials used in the structure of Costa Rican buildings.

C. Conduct physical inspections to collect real data (rather than theoretical) on building content.

D. Find and calculate accurate emission factors of various items.

We decided to create the categories of buildings for our warehouse, industrial, and hospital models in our app after our interview with Sr. Ramos and research about different types of industries in Costa Rica (Section 2.5). We found that dividing buildings based on the contents would give us a more organized approach in calculating their carbon emissions. This is because the biggest variation amongst structures was the contents inside them. Instead of having an average of emission factors to use in the calculation of CO_2 emissions for all warehouses, for example, we would use the emission factors of the materials in each warehouse category to have a more accurate result. To make these categories, we researched the most prevalent types of warehouses and industrial buildings as well as differences amongst hospital types in Costa Rica. These categories and a further explanation of why we divided them as such will be explained in their respective sections (3.3.1, 3.3.2, 3.3.3).

We conducted interviews with two civil engineers, Angela Solarte and Esteban Ramos of SHPI Ingeniería, to have a better understanding of the types of materials used in the buildings we were working with. This provided us with information about the structure, such as the interior walls, exterior walls, doors, ceilings, etc. We needed information on the different materials used in constructing warehouses, industrial buildings and hospitals so that we could use the information to calculate the CO_2 emissions from structural fires. We made sure to ask non-intrusive questions about the materials generally used in the construction of buildings in Costa Rica when conducting our interviews. Doing this allowed us to gain general knowledge about structures specifically in Costa Rica without invading the privacy of specific companies. The questions for these interviews can be found in Appendix B.

While the interviews with the civil engineers gave us an accurate representation of the structure, we still needed to get information about the content in different buildings as well as building layout. As the previous group suggested, we conducted various physical inspections as part of improving the models. We agreed with the previous group that this was an important step in improving the models since they were currently only based off of theoretical data, making them extremely inaccurate. This method was useful to gain more specific data on the structures that our models would be used on. We performed physical inspections of buildings that fell under the categories we had created for our industrial and warehouse models. On these inspections, we made sure to examine building content as well as different types of rooms located throughout the building. Content material is defined as anything in the building that is not part of the structure: for example: machinery, products, storage material, etc. Physical inspections were important in helping us to complete our inventory of possible materials for each category. We made sure to have an accurate depiction of the contents by creating worksheets that helped us track and organize accordingly the contents in each subcategory (Appendix C).

In order to create those worksheets, we went back to the calculations and figured out what variables are needed to calculate CO_2 emissions. Emissions factors are essential to the calculations and those depend on the materials. For this reason, the two main parts of those worksheets are lists of materials used in structure and materials found in the contents of the buildings. The separation between structure and contents was made because the contents of each building are what places them in different subcategories. We researched various websites and reports to find the emissions factors that were necessary in accurately calculating the carbon emission from a warehouse or industrial fire. Through our research, we found that not all emission factors could be easily found. We needed to do more work later on to calculate unknown emission factors in order for our app to produce accurate results.

While we were inspecting, we made sure to be weary of each company's privacy. The purpose of those inspections was to better understand the contents of the different categories. Upon entering each building we inspected, we agreed with the staff that they can remain anonymous in our report and also that we wouldn't enter or document any parts of the building that were private. While performing a physical inspection on an industrial building, we were told we were not allowed to take photos of anything we were being shown. This was somewhat inconvenient since we typically used photos from our inspections, as well as notes, to determine information needed for the model, but we abided by their rules in order to respect their privacy.

3.3.1 Warehouse Model

The previous warehouse model only took into account the primary structural material and type of good stored in the warehouse. It did not allow the user to input specific items or use multiple categories. These things needed to be changed in order to improve the accuracy of the model when calculating carbon emissions. We decided to conduct physical inspections of various types of warehouses, and keep track of types of rooms, products, and how the products are stores using the inspection worksheets found in Appendix C.

The hardest part of calculating emissions using the warehouse model was getting a good estimate of the fuel loading. The fuel loading of the warehouse is defined as the amount of material stored in the warehouse. In the main storage room of a warehouse, the fuel loading consists of the product of the warehouse, its packaging and the shelves where the products are stored. During our inspections we recorded the types of materials used in shelving and packaging as well as the variety of goods stored in these warehouses.

We divided warehouses into categories. The categories are food/drink/tobacco, textile/leather, wood, metal, paper, chemicals, electronics, combustibles, and plastics. These categories were chosen after various physical inspections and research about warehouses using the warehouse's website. Our sponsor agreed that these were the best categories to include for warehouses based on his knowledge of types of warehouses in Costa Rica. Once these categories had been established, we made subcategories for each category that listed more specific products under that category. Both categories and subcategories were designed by using information from physical inspections as well as common knowledge. When inspecting warehouses, we went through every aisle and chose an overall category for each aisle. After each aisle was assigned a category, we began sub-categorizing the items in each aisle. For example, in an aisle categorized as food/drink/tobacco, we found boxed milk, canned vegetables, and 1lb bags of rice. Other food aisles had different types of products. This process led to us creating the following subcategories of food/drink/tobacco: alcohol, grains, fruits/vegetables, meat, dairy, and canned goods. The subcategories help the user to get more specific when inputting information about a warehouse. This in turn leads to a more accurate calculation of total carbon emitted from a warehouse fire.

3.3.2 Industrial Model

The previous industrial model calculated CO_2 emissions by taking into account the type of material that is processed in the building. It left out the structure and any other materials in the industrial building. To improve the accuracy, we made sure to account for all these omitted aspects. After performing physical inspections, we discovered different aspects of factories that we believed should be included in the calculations when calculating carbon emissions. These included different rooms, machinery, content materials, packaging material, and any other factors we found during our physical inspections. During our visits we kept an inventory of the types of rooms encountered and the contents of each room. The information from the physical inspection worksheets (Appendix C) completed the Java application with the emission factors of each room in each building. The physical inspection sheet took in account every aspect of the building as well as organized our findings.

Visiting one factory from each subcategory was proven unrealistic once we arrived to Costa Rica. Due to the limited time and difficulty in organizing visits to a large number of factories and power-plants, we limited our visits to two. Those two visits were not enough to create accurate categories of industrial buildings in Costa Rica. Our method of creating those categories was through extensive research of the data of Camara de Industrias Costa Rica (CICR). This organization keeps track of all the industries in Costa Rica. They have created a database with all the industries on their website which we consulted to make a list of all the industries and form meaningful categories. On their website, CICR has a list of categories that enable the user to search for specific registered industrial buildings in Costa Rica. We went through this list and based our categories off of the options given by CICR.

We started by creating two categories of the industrial model, one for factories and one for power generation plants. However, we discovered that the power plant subcategory was not urgent enough to start our inspections with it. Ultimately, we did not have time to work on adding the category so we included it as a future recommendation. Costa Rica currently has 32 hydroelectric power plants that account for more than 90% of its energy production (Global Energy Conservatory, "Current List of Hydro Power Plants"). The main “processing material” of those power plants, water, is not combustible. However, power plants that burn petroleum and natural gas that exist in Costa Rica would have emissions due to those fuels. The offices, maintenance rooms and structure are the same (International Building Code, 2007). We ended up only using factories in the industrial categories.

3.3.3 Hospital Model

Due to limited time, we did not perform physical inspections of hospitals while in Costa Rica, and therefore were not able to refine the hospital model. Although we didn’t have time to complete this model, we had come up with ideas on how to refine it. To refine the hospital model, we believe it should be reclassified into three categories—urban, rural, and assisted living facilities. Further research is required in order to confirm that these categories are an accurate representation of Costa Rican hospitals. Hospital buildings are typically constructed of nonflammable materials, but it is also permitted by law to use combustible materials for their construction (Understanding the importance of construction types, 2011). We believe there is a chance that hospitals in rural areas are constructed using flammable or combustible materials to reduce cost. Assisted living facilities are a separate category because we found that the structure is often more related to a residential building, while the content falls under the hospital category. We think that a hospital that falls under each of these categories should be inspected to determine each type’s structural material and contents. Different rooms should be noted as well during these inspections.

3.4 Objective 3: Improving User Friendliness and Limited Input

User friendliness and accuracy are very tightly connected in this Java application. In order for the results to be accurate, the user must input as much information as possible about the building that was burned. To improve user friendliness and limited user input, we used the following methods:

A. Experiment with inaccurate models and take note of information inputted by the user.

B. Go through residential model and decide what made it more successful.

C. Host a focus group in order to get valuable feedback on the user friendliness and aesthetics of our models.

In order for our team to gain better insight on the Java application, we needed to experiment with the application ourselves. To do this, we acted as end-users for the models and ran the application for an industrial building. As we used the application and examined the user input fields, we decided on ways we could improve it. The previous model takes as input the area of the building and its primary use. The end results are much higher than one would expect. When we experimented with the industrial model, we got a carbon emission of 86,000 metric tons for a simple industrial building. This result is impossible since the annual carbon emission from structural fires in Costa Rica in 2013 was about 34,000 metric tons. On the figure below one can see the limited fields of input for the previous industrial model.

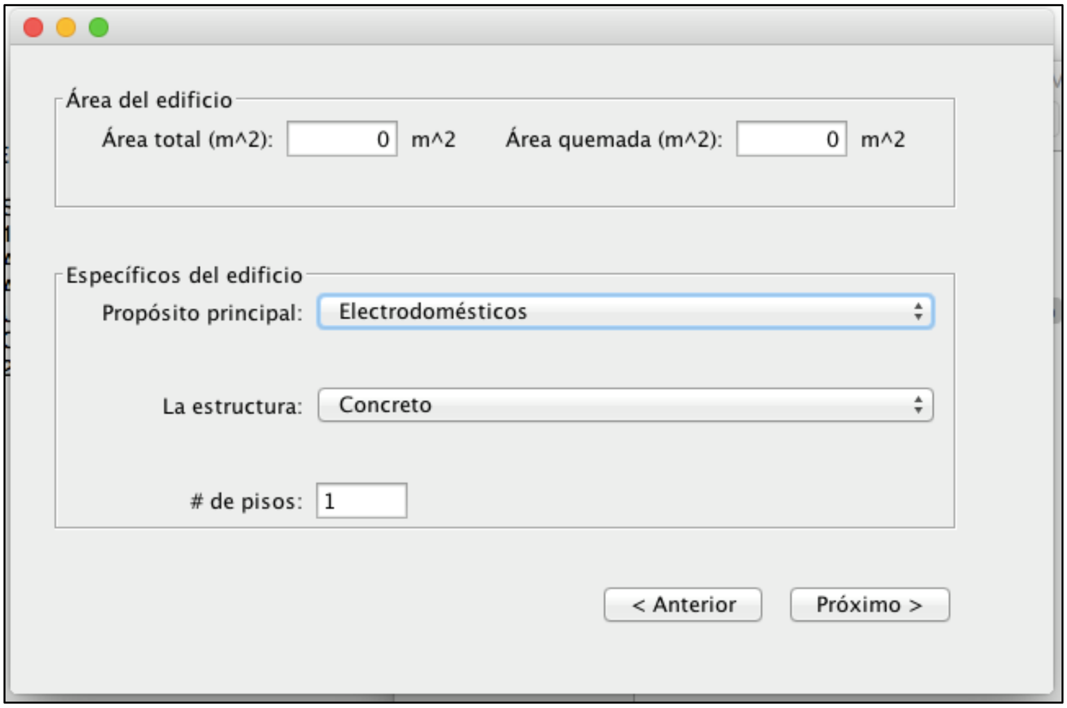

Figure 6: Previous Warehouse Model

In this model, the user only inputs total area, area burned, type of warehouse, primary structural material, and number of floors. Although these factors are all important in the calculation of CO_2 emissions, there are other factors that also need to be taken into consideration in order to make the model more accurate. For example, an electronics warehouse with a concrete structure and area of 1000 m^2 provides a rough estimate of how much carbon would be emitted if the building was burned down, but if we consider the different types of electronics in the warehouse, how the items are stored and displayed, and other materials used to build the structure, we have a more accurate sense of how much carbon it would truly emit if it was to burn down.

We examined the residential model, which was successful in predicting CO_2 emissions. The residential model has numerous inputs by the user including all the rooms of the house and, for each room, all its contents. This method of approaching carbon emissions room by room was successful in the residential model and for this reason; we decided to adapt it for the industrial, warehouse and hospital models as well. As mentioned in section 3.3, there were different types of subcategories and rooms in the buildings our team was working on. The user should have all those options as input.

To further examine user friendliness, we conducted a focus group. We had participants from both SHPI and Bomberos during the focus group. The goal of this session was to get feedback on how easy the application was to use and understand. These two factors are vital in the success of our application in order for input to be valid and results to be accurate.

During the focus group, we gave each participant a made up case study about a fire at a warehouse and asked him or her to each use the application to calculate the total carbon emission from that fire. We compared their answers to our answer, to see if they were using the application correctly. We then handed out a small survey to get feedback on the user friendliness. The questions of the survey can be found in Appendix D. In this survey, we asked users to rank both the user friendliness and aesthetics of our application, as well as offer suggestions on how to improve the application and user experience. The feedback from both SHPI and the Bomberos was very important to us, since they will be the primary users of this application in the future. The answers to these questions helped us to further update our models to ensure the user understands the application and will be able to achieve accurate results when using it.

3.5 Objective 4: Verifying Improvement of the Models

Verifying the models was a challenging task due to the lack of warehouse and industrial models to predict CO_2 emissions from structural fires. The lack of information on the emissions of fires created problems in verifying our models because we did not have case studies with known numbers. We had to be creative in our methods of evaluating the accuracy of our results. In order to verify our models, we used the following methods:

- **A.** Compare our model to previous model developed by WPI students.
- **B.** Compare our model to one created by EPA.
- **C.** Prove mathematics of our models with hand calculations.

To verify that our model was improved, we needed to prove that it was more accurate than the previous model created by WPI students. We did that by entering the same information to the two models and discussing the result. We had to create a "fake" warehouse to perform that method. The way we evaluated the results was by discussing how realistic they are based on the known data we have about overall CO_2 emissions in Costa Rica. We can judge how realistic the emissions are based on the total estimate of carbon emitted from structural fires annually and the number of fires that contribute to the annual emissions.

Next, we compared our models to the one created by EPA that is discussed in section 2.5 of the Background. The reason we chose this model was because it is generic and can be used for many types of buildings. The rest of the models that we found in our research only applied to residential buildings. Since, again, we didn't have a known study to use, we compared the calculations within the model and the amount of averages used. If a calculation uses more averages, it is less accurate is it doesn't take variations into consideration. The reason we explored the averages is because a model using many of them will not be as accurate due to the fact that it does not take into consideration many variations.

Since we did not have a real case study to compare our model to, we needed to prove it worked mathematically. To do this, we compared our application with hand calculations using the same numbers. We made sure this way that the application uses the number input the right way and the end result is the same as doing each step of the calculation by hand.

3.6 Objective 5: Provide SHPI with Methods to Improve Models

SHPI Ingeniería needs a tool to keep evaluating the accuracy of the models once we leave Costa Rica. This is because over time new products will be created and building codes can change. These changes will call for the databases for contents and materials to be edited and updated. For this reason, we designed a series of instructions to keep filling these databases. With the prospect of change in the future, we cannot guarantee that our models will be accurate forever.

Several SHPI personnel expressed interest in understanding how the application works from a technical point of view. Being engineers, they understand technology and coding to a certain extent and would like to learn how to manipulate the application for future reference. Unless they were to take a class teaching them Java, they will not be able to fully understand every line of code. For this reason, we added non-executable comments throughout the program to explain each line of code in non-technical terms. This will help SHPI personnel learn what each line of code does without having to learn the entire Java program. In addition to the non-executable comments, we provided SHPI with a sheet of instructions further explaining how to write and edit Java. In this sheet of instructions, we will explain where to edit the code in order to make the right changes. We will list specific lines throughout the code, what they do, and how to go about changing them. Using the non-executable comments and written instructions will give SHPI personnel Java skills that are proficient enough to update certain aspects as well as add new materials.

3.7 Final Deliverable

The final deliverable result of this project was two updated models to calculate the emissions from structural fires in Costa Rica. These models come in the form of a Java application. Those applications prompt the user for information related to the structure in question, such as structure size, types of rooms in structure, primary structural material, contents and more. This information is used, along with the data we collected from our inspections, to provide a numeric approximation of the carbon emissions in the event of a structural fire.

Along with the two Java applications, this project furnished the sponsor, SHPI Ingeniería with methods to keep all models updated to current statistics. The methods employed ensure the accuracy of the models for the foreseeable future, and make sure they are providing reliable, consistent results.

4. Data Collection and Model Development

In this section we explain how we used the data we collected to update the warehouse, industrial and hospital models. The development of the updated models consists of two main parts: increase of accuracy and improvement of user friendliness.

It is important to know the general calculation for CO_2 emissions for our models to follow our data collection and model development section. As a result of investigating formulas from existing models in the methodology section, the equation we decided used is the following:

Equation 1 - CO2 emissions calculation: *Mass of CO_2 (e)= Mass of burned material (b_m) * emission factor of material (f)*

It is the same equation as the one used in the residential model.

We also used the density equation in our calculations. For the purpose of this paper, it is labeled as **Equation 2.**

Equation 2 - Density calculation: *mass (m) = density (ρ) * volume (v)*

4.1 Emission Factors

Emission factors of different materials are a very important variable in our calculations, as seen in equation 1. The emission factor of a material represents the mass of CO_2 emitted per mass of the material when it is burned. We devoted a large part of our data collection to researching the emission factors of all the contents and structural materials that were encountered during our physical inspections in different types of buildings. Most of the emission factors were obtained from the Environmental Protection Agency's (EPA) website, from their various studies on materials.

There is a series of products for which emission factors have not been calculated. For these products we took it upon ourselves to implement a series of calculations that allowed us estimate an accurate emission factor. An example of a product that we calculated the emission factor for is a gallon of milk. This is a standard product that should be treated as a single unit. This unit contains the packaging used, as well as the milk itself. In this example, the emission factor was generated by our team after a series of calculations where we took into consideration the fat content of the milk, as well as the plastic container used to package the product. Then by adding these two separate calculations, we were able to estimate the carbon dioxide emissions from one gallon of milk, packaging included. Similar calculations were made for canned goods, packs of meat, alcoholic/carbonated beverages, and other dairy products. For canned goods, we used the average mass of the canned product and the mass of the can itself, multiplied by the appropriate emission factors. For packages of meat we included the emission factor of the physical meat, as well as the packaging the meat would come in (plastic wrap, styrofoam).

Emission factors of typical household appliances and objects such as computers, refrigerators, tables, and chairs, could be duplicated from the residential model developed last year, as the average masses and emission factors remain constant between different types of buildings.

4.2 Creating a Material Database

In order to add the emission factors to the model calculations, we organized the factors in a database. During physical inspections, we used the inspection sheets to take not of all the products and materials in industrial buildings and warehouses. We transferred all the materials to a database where we arranged them in categories of similar materials. Examples of categories are food products, chemicals, paper products, and metals. We populated the database with the emission factors discussed in section 4.1. The end result was a database with categories of materials, the emission factors of each material and an average emission factor for each category of materials. The purpose of this database was to organize all the available materials with their corresponding emission factors, so that whenever the application required input of this data, it could be easily taken from the database. Appendix E shows part of the material database we designed.

There are two types of entries in the database: raw materials and finished goods. An example of a raw material entry would be "wood" and a finished good would be "computer". For both types of entries, the emission factor corresponding to the entry is in mass of CO_2 emitted per mass or volume of material or product. Many of the products, especially appliances, also have a standard mass for one unit of that product type. This entry serves to calculate the CO_2, emissions per unit. For example, the emission factor of computers is 1.8 kg CO_2 / kg. The standard mass for a computer is 3 kg, therefore 5.4 kg of CO_2 would be emitted if a computer were to be burned (equation 1).

The database also includes the densities of many materials. The density is used to calculate mass from a given volume (equation 2). In many cases, the volume of material is known, however the mass is not. However, the mass is the physical property used in the calculation of emissions (equation 1). Therefore, the densities of materials are used to easily migrate from volume to mass throughout our calculations.

4.3 Increasing Accuracy of the Models

Our primary goal for this project, as stated previously, was to improve the accuracy of the warehouse and industrial models based on the results of our research, interviews with our sponsor and recommendations from the previous group. The previous models were based on theoretical data obtained from case studies in different countries, and because of this, produced results that were inaccurate. Due to the lack of data specific to Costa Rican buildings, the models made assumptions and used averages of values that were not accurate. As an example, the average of shelf size in the warehouse model was not accurate, so it yielded an exaggerated amount of CO_2 emissions from the warehouse shelving.

Additionally, in the previous models, the user could enter only one primary material for the structure of the building. This limited amount of user input also lead to inaccurate structural emissions since, as we learned from research and our two interviews with civil engineers, warehouse and industrial structures in Costa Rica often contain insulation, in addition to the primary materials, that yields significant amounts of CO_2 when burned. These emissions were not accounted for in the previous models.

As seen in the description of the residential model in section 3.2, the emissions of structural fires can be split into structure emissions and content emissions. We found this division helpful since the structure and contents of a building are two separate factors and they contain different materials; structure is normally concrete, steel and polystyrene whereas contents can be anything from food to chemicals. In the following sections we explain the modifications we implemented in terms of structure and content emissions calculations in the warehouse and industrial models.

4.3.1 Developing the Warehouse Model

In this section we discuss our data analysis that resulted in the updated warehouse model. We explain the calculations made to estimate CO_2 emissions of the structure and contents of a warehouse. The methods we used to improve this model were physical inspections and interviews about structure; details on the results of those methods can be found in the respective sections.

The end result of this section in an updated warehouse model. The model is incorporated in an application that is organized around three types of input from the user. The first one asks for information on the structure, the second one is about secondary rooms and the third one relates to shelving units with products. The following screenshot (Figure 8) shows the first page of the warehouse model with the three types of user input ("Nuevo Material Estructural", "Nueva Área Afectada" and "Nuevo Estante Afectado"). Throughout the section we describe the logic behind those three types of input.

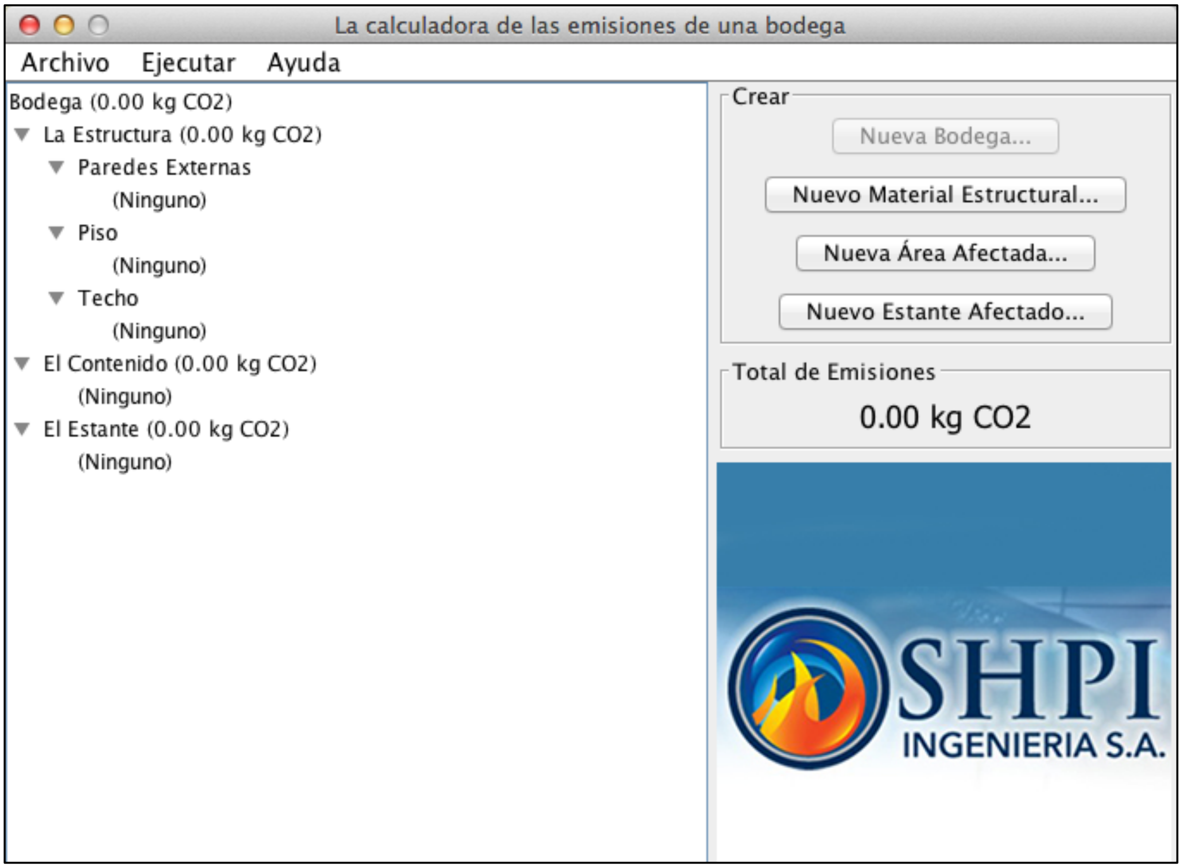

Figure 7: User Input Types in Warehouse Application

4.3.1.1 Calculating Emissions from the Warehouse Structure

In this section, we explain our findings from our interview with two civil engineers, Ing. Esteban Ramos and Ing. Angela Solatte, engineers from SHPI Ingeniería, on the materials used in structures of buildings in Costa Rica. Additionally we expand on the results of our research on the same topic. Finally, we explain how the data we collected shaped the structure emissions calculations in the updated warehouse model. This section refers to the first type of user input, as seen in figure 8 ("Nuevo Material Estructural").

The previous warehouse model asked only for input on the primary structure material of the building. The material was most likely concrete, which produces no emissions. This approach does not take into account the materials in the structure that actually produce CO_2 emissions when burnt, which lead to an inaccurate result. Through our research and interview on the topic, we collected information that helped us come up with an improved approach of calculating the emissions from the structure of a warehouse.

The structure of warehouses and industrial buildings in Costa Rica are very similar. The two main materials used in the construction of warehouses and industries in Costa Rica are concrete and steel. This is information we received from our interview, and also cross checked with documents from the Treasury *(Ministerio de Hacienda)* that describe the construction materials used in Costa Rica (Ministerio de Hacienda, "Manual de Valores Base Unitarios Por Topología Constructiva", 2013). The civil engineers we interviewed both recommended this document as a source for the types of materials found in Costa Rican buildings. According to our interviewees, the newest buildings also include a plastic material called polystyrene. Polystyrene is used in the construction of either the roof or walls of the building to offer insulation. Although this material is not included in the Treasury manual, we decided to include it in the available options for structural materials, since we learned from our interviews that it is use is common in newer buildings in Costa Rica.

As seen in figure 8, structural materials are one of the three inputs of the user in the application. Initially, we intended on creating a pre-determined structure depending only on the area of the building. This option would omit important information such as the presence of polystyrene as well as the amount of other structural materials present in the wall. We decided to create this input in our model, rather than having a pre-determined structure, because our findings from the interview indicated that each building has a different composition of the same materials (concrete, steel, polystyrene). Also, each building has distinct amount of insulation, which can be composed of different types of polystyrene insulation.

In our warehouse model, the user inputs the structural materials of the warehouse by selecting them from a list. This list consists of the materials that Ing. Solarte and Ing. Ramos suggested as well as the ones found in the Treasury manual. Those would be concrete, steel and polystyrene. There are three distinct entries for polystyrene, based on their different R-values. The R-value of polystyrene is an indication of its insulation capabilities and a high R-value means that the material insulates better. In terms of emissions, concrete releases no carbon when burned, and steel has a very small emission factor (0.0117 kg CO_2/kg steel) due to the fact that it contains only small amounts of carbon. The major source of emissions in the structure is polystyrene. This fact confirms that our decision to include it despite its absence from the Treasury Manual was valuable to the accuracy of the model.

We decided to break down the structure of the building into roof, external walls and floor, as the materials that may compose these sections of the building differ from one section to the next. The screenshot below (Figure 8) shows the form where the user selects which part of the structure they want to add a material to.

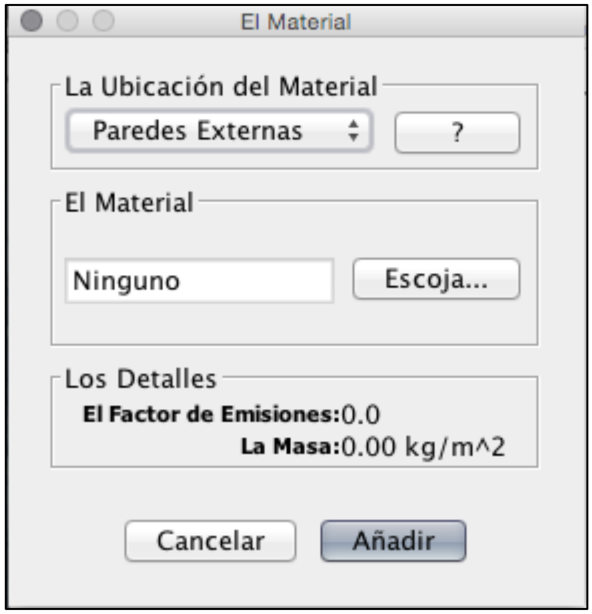

Figure 8: Structure Selection Window

When the user clicks on the button labeled as "escoja" (select), a new window opens with the materials selection. The window is as follows (Figure 9):

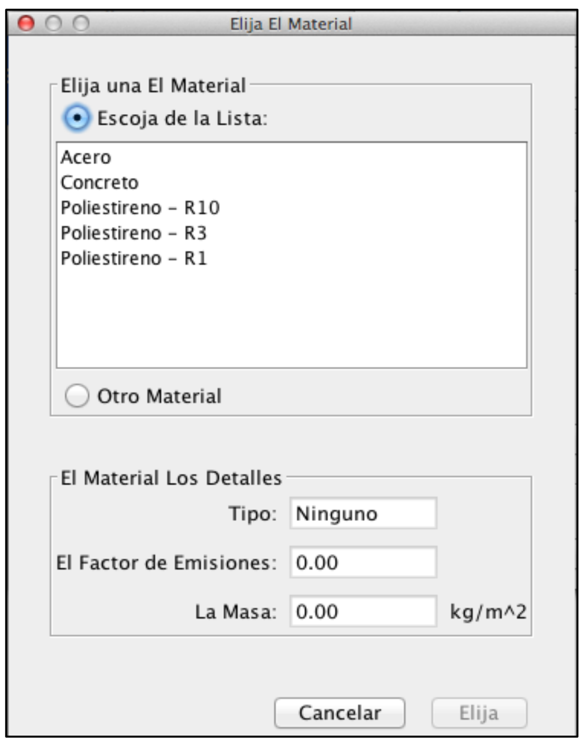

Figure 9: Structural Material Selection Window

In this dialog box, the user selects the material they would like to add to the structure. The program adds the material selected to the structure, and records the materials surface density (mass per unit area of structure) and emissions factor from the material database. The surface density of the material is highly important, as it is used to calculate its mass using the area of the structure (similar to Equation 2). The mass of the material is needed for Equation 1**.** Knowing the surface density, the area of the building and the emissions factor for the given material, the model calculates the CO_2 emissions from the structure. Polystyrene has an emission factor of 1.67 kg CO_2/kg, and the emissions factor of steel is 0.0117 kg CO_2/kg. Therefore the majority of the emissions from the structure of a warehouse are caused by its polystyrene insulation.

In figure 9, one can notice that we provided an option labeled "Otro material" (other material). This feature gives the option to the user to input a new custom material. We decided to provide it in case the warehouse in question is constructed from non-standard materials. The user would be expected to provide information relating to the material on their own, since the application requires the emissions factor and mass per unit area of the material. We assume that since they have detailed knowledge about a special material in the structure, they would also know the required details for that material. We included this feature to make sure that every single source of emissions is accounted for, even if it comes from a material that is not normally used in warehouse construction.

4.3.1.2 The Effect of Warehouse Layout on its Carbon Emissions

In this section we present our findings on the layout of the warehouses we inspected, and how these findings have influenced several features in our application. We visited three warehouses as part of our physical inspections. Two of them were commercial warehouses, and the third was an electric cable warehouse. During physical inspections we observed the layout of warehouses and the secondary rooms located within them.

Upon physical inspection of the three warehouses, we discovered that warehouses in Costa Rica are not exactly what we had hypothesized. We had made the assumption that a warehouse was a storage unit containing only similar items. Although this was true for some warehouses we visited, it was not true for all of them. The two larger warehouses we visited were commercial warehouses that the general public shopped in. These commercial warehouses contained many different categories of items rather than only one category. The fact that commercial warehouses contain more than one category of products means that we needed to develop a way for the user to enter all the distinct types of products found in the warehouse. The option of selecting a category of products for the whole warehouse was no longer viable.

The majority of the warehouses we inspected were composed of shelving units that contained products. We investigated the shelving used in the warehouses we inspected to collect information that would help us develop the shelving unit input. Commercial Warehouse A had a total of 513 shelving units and Commercial Warehouse B had a total of 355 shelving units. The single product warehouse was much smaller, with only 50 shelves. We found that the height of the shelving units in all warehouses were the same (or extremely similar), and that there were 5-8 shelves on each shelving unit. The complete list of shelf dimensions and their averages can be found on Appendix F. We realized that the dimensions were all very close, due to the fact that there are standard shelving unit vendors in Costa Rica that provide shelving to most warehouses, according to the information the warehouse managers gave us during inspections. After collecting this information, we decided to introduce the shelving unit as a means of entering contents in the warehouse. The consistency of the shelving dimensions throughout the warehouses we inspected lead us to this decision.

Our approach of entering shelving units makes it possible to use the warehouse model for both commercial warehouses and single product warehouses. The user has the option to input the dimensions of the shelving units in their warehouse or select the average default dimensions of shelving units in Costa Rican warehouses that we calculated.

Each shelving unit that we encountered during our inspections was made of four square steel rods that support a number of shelves (as mentioned previously, usually 5-8). These shelves could be made of wooden pallets or wood planking, depending on the warehouse. Within the same warehouse, the type of shelf construction could differ from unit to unit. Some of the shelves did not have a base and only consisted of the metal skeleton. These were normally shelves used to store large pieces of raw material (pipes, concrete blocks, compressed wood pallets, etc.). In the food sections of commercial warehouses, some products were stored in refrigerators. Therefore, we included the option of a refrigerator shelving unit. The dimensions for the refrigerator option are the same as the normal shelving unit. This is because the dimensions for a standard refrigerator were included in the calculations for the average shelving unit dimensions. In essence, we treated refrigerators as shelving units with the emission factor of a refrigerator. The options for inputting the information relating to the dimensions and materials composing the shelving units are demonstrated in the screenshot below (Figure 11):

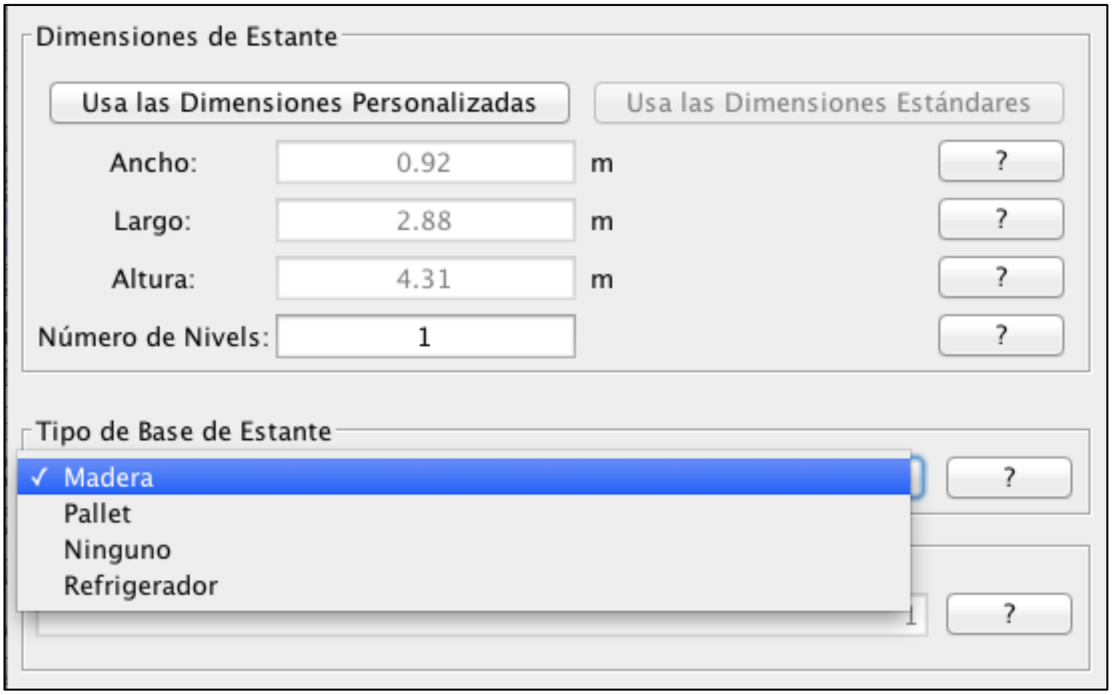

Figure 10: Input Shelving Unit Dimensions and Base Type

The model uses the information from figure 10 to calculate the CO_2 emissions from the shelving unit. CO_2 is emitted by the burning of both the shelves themselves and the products stored on them. The dimensions of the shelves are essential for the calculation of their mass, which is needed for the emissions equation (equation 1). From the dimensions our model calculates the mass and then multiplies that by the emission factor of steel or wood, according to equation 1. An example calculation of the CO_2 emissions from a shelving unit can be found on Appendix G.

The previous warehouse model did not account for the secondary rooms in the warehouse. However, as we discovered during our warehouse inspections, there are always other rooms in addition to the main product storage area. We investigated the rooms found in the warehouses we inspected to include their emissions to the total. The area of each room was measured during our physical inspections. We then used the dimensions of all the rooms of the same type to calculate average areas. The types of rooms we encountered in our warehouse visits and their average areas are found in Table 2:

Table 2: Types of rooms in Warehouses

Type of room	Area (m^2)
Break Area	10.0
Office	8.70
Conference Room	15.0
Cubicle	2.75
Bathroom	2.16

Information on the different types of secondary rooms is essential to the accuracy of the models, since all rooms have content that contributes to the total emissions of the building. During our inspections we realized that all warehouses had at least one administrative office and bathroom and the larger ones had up to 10 offices. The contents of those rooms were wooden desks and chairs, paper, computers and cabinets. Similarly, bathrooms were always present and they contained toilets, sinks and cabinets. An accurate calculation needs information on the contents of the room. Therefore, when the user inputs secondary rooms using the "Nueva área afectada" option from figure 7, they are asked to add furniture to these rooms. In the following example, we demonstrate the user input for objects in an office.

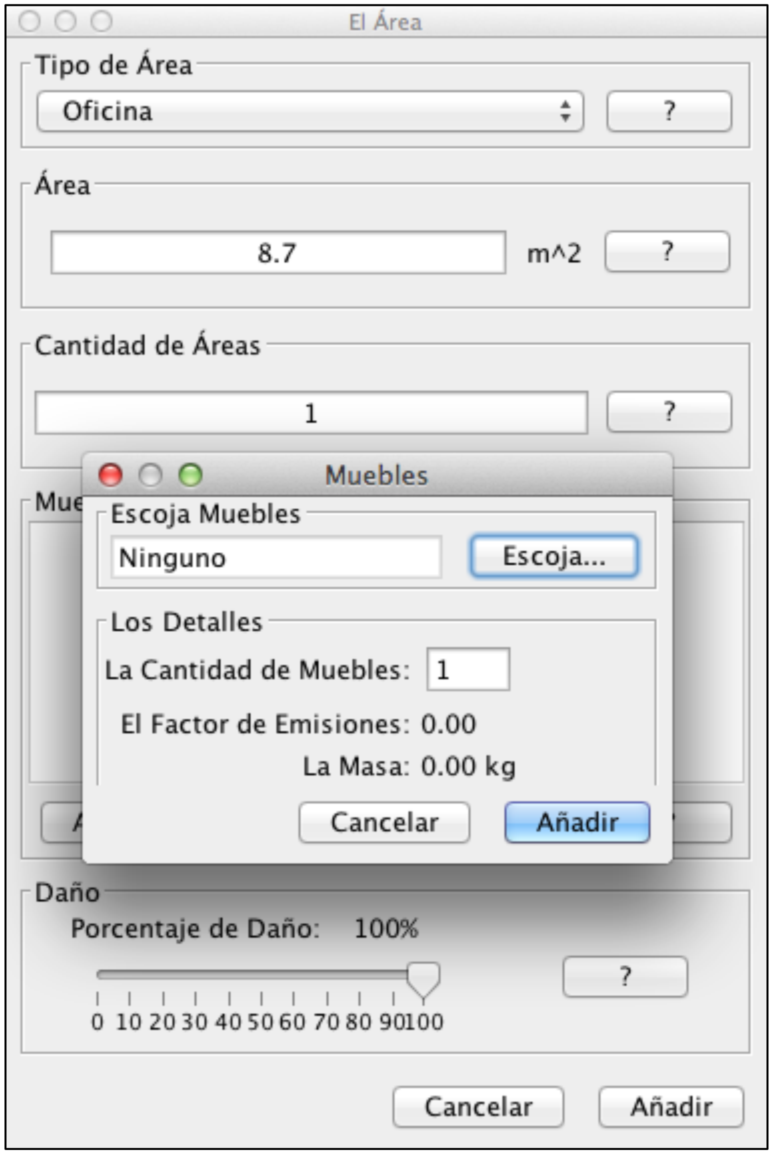

Figure 11: Input Secondary Areas of Warehouse

In Figure 11, the user has selected to input information on an office. The first box is preset to the average area of the type of room, in this case office, from Table 2. However, the user is able to change that if needed. The average value ensures that the field is not neglected if a user does not know the area of the specific room they are describing. The second box represents the number of offices found in the warehouse. The percentage bar in the end indicates the percentage of the room that was damaged. The pop-up box in the middle is where the user would click on "escoja" to add furniture. The list of furniture can be seen in the next screenshot (Figure 12).

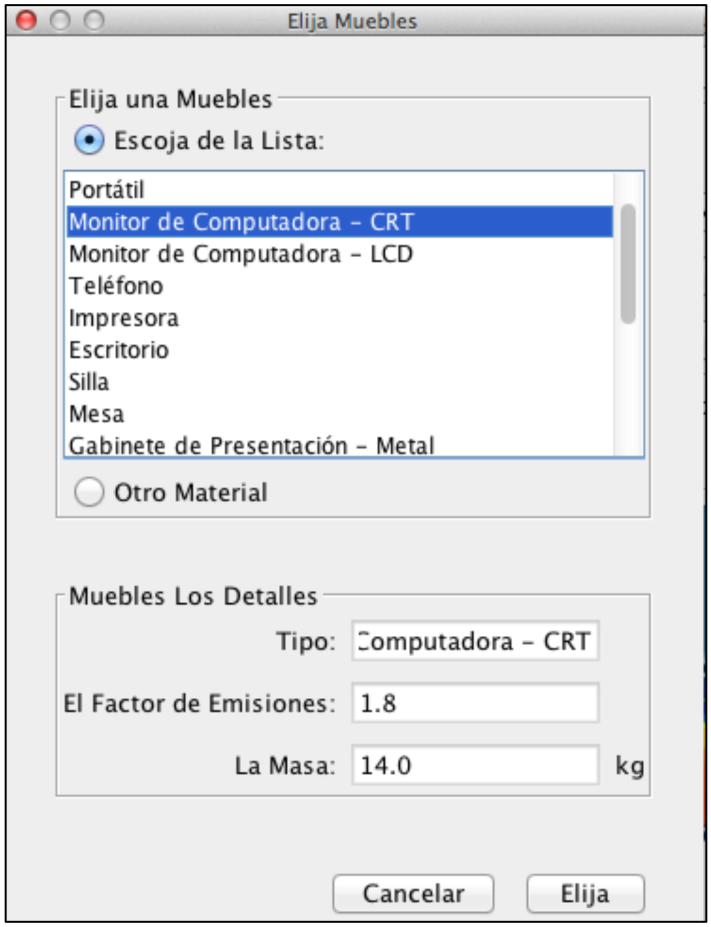

Figure 12: Selection of Secondary Room Content

Every time the user selects an object, the program retrieves the emission factor for that object from the materials database. The emission factor, again, is essential for the calculation of emissions for the room. The calculations for the emissions of the secondary room are similar to the ones in the residential model. For the offices, for example, the user can select one by one the contents of the room (desk, chairs, computer, etc.) and the model calculates the CO_2 emissions based on the emission factors for each individual item. In order to make user input of each secondary room less overwhelming, we added a default room loading (average contents) for each of those rooms. The default option is explained in detail in the user friendliness section.

4.3.1.3 Warehouse Content Emissions

In this section we explain how we collected data on the contents of the warehouses we inspected and how we used this data in the calculations for content emissions.

The contents of the commercial warehouses varied everywhere from electronics to food. Inspecting these buildings gave us a good idea of the types of products stored in warehouses in Costa Rica. We enhanced that information by visiting the websites of the commercial warehouses we inspected, as well as their equivalents in the United States.

With our physical and virtual visits of the warehouses, we were able to find a great number of different products with which to populate our materials database. Using the materials database, we were able to create categories of products and materials found in warehouses. We also calculated the average emission factor for each one of those categories. Table 3 shows the categories of warehouse contents and their emission factors.

Table 3: Emission Factors for Warehouse Categories

Subcategory	Emission Factor (kg CO_2 / kg)
Food	2.90
Metal	0.01
Wood	1.50
Textile	1.05
Paper	1.50
Chemicals	1.67
Electronics	1.80

We organized all the products into these categories due to the fact that shelving units, more often than not, contained multiple types of products, that were similar but not identical. By having an average of "food" emission factors, one can calculate a very close estimate of the carbon emissions of several products that fall within that category and are stored on the same shelving unit. For example, if a shelving unit contained canned beans, pasta and tomato sauce, the average emissions factor for food multiplied by the mass of the products on the shelves would give a very close estimate of the CO_2 emissions. It would be quite difficult for the user to input every single type of food on every single shelf for large warehouses. Using average emission factors for categories is the most effective way of calculating an accurate number for emissions without having to each individual product.

We created two methods of user input for contents on the shelving units. The user can either select a subcategory of products that fall within the category or the average for the category of products. The purpose of this is to gain as much accuracy as possible. If, for example, the specific shelving unit has only canned goods, the user selects the "food" category, and then is directed to a second menu where they can select the "canned goods" subcategory. This second selection increases the accuracy by only using the emission factor for canned goods in the content emissions calculation. If, however, the type of food that is on the shelving unit is not on the list, or if the shelving unit contains more than one different types of food the average emissions factor from Table 3 is used. The result is still accurate since the average is created using materials of a similar type.

The screenshot below (Figure 13) shows an example of the selection process for the type of contents on the shelf. The first list is the general category (chemicals) whereas the second list breaks that down into subcategories. The last entry of the list is the option for using the average emission factor for the category (denoted with asterisks).

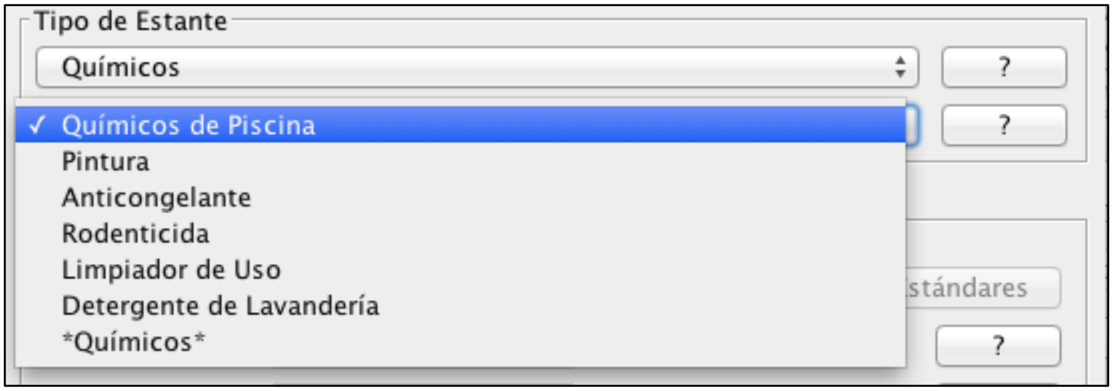

Figure 13: Selection of Category and Subcategory of Warehouse Contents

Calculating the emissions of the products on the shelf is complicated due to the lack of inventories in many warehouses. Inventories can offer an accurate count of content for any warehouse. While inspecting warehouses, we asked managers if the building had an online database that listed the inventory. This is especially important for the commercial warehouses, since an interview with the building manager revealed that they stocker over 16,000 items. Having an updated inventory is extraordinarily helpful in accurately calculating the warehouse's carbon emission, as the user must know what materials were available as fuel when the fire occurred.

Two of the warehouses we visited had inventories, while one warehouse claimed to not to. We decided that our calculations should not rely on the existence of an accurate inventory, and thus needed to find another way to calculate the mass of products stored in the building. We used the relationship between volume and density to calculate the mass of products on a shelf (Equation 2). From the shelf dimensions, we can calculate the volume of materials that the shelving unit fits. From user input we know the type of material that is stored, and therefore its density from the materials database. In order to find the mass of material stored in each shelving unit we multiply its volume by its density, using Equation 2. We then multiply that by the emission factor for the specific type of product selected. An example calculation of shelving unit contents can be found in Appendix H.

4.3.2 Developing the Industrial Model

In this section we focus on our findings from the industrial building inspections and how they shaped the updating of the industrial model. Since we developed this model after the warehouse one was completed, we include in our analysis a comparison between the two. During our inspections of warehouses and industrial buildings we noticed the similarities between the buildings, and these similarities are highlighted in this section.

Similar to the warehouse model, during our inspections we collected information on each type of room in the factories we visited. We also collected information on the raw materials used in the factory, the types of machinery and the energy sources (e.g. fuel) used in production. We collected information about raw materials through an interview with a facility staff member, who guided our tour through the factory. We also took note of all the labels of raw materials during our tours. The types of machinery were harder to track, because of a lack of available information from our guides about the specifics of the machines. We expand more on how we dealt with this challenge later in this section. We researched the types of industries in Costa Rica using the Cámara de Industrias database. This information was translated into our list of industrial building categories, which will be elaborated on next.

4.3.2.1 Industrial Building Categories

Based on the industries registered with Cámara de Industrias, the all of the industries in Costa Rica fall within the following categories: food/drink/tobacco, metals, plastics, chemicals, textile/leather, glass, construction materials, power plant. The database has categorized the industries to enable their database to be search. We decided to use the same categories for our model since the Cámara de Industrias is a reliable organization that includes most, if not all, of the industries in the country.

For each of the categories, we also noted the main types of factories that fall within them. When the user chooses what category the industrial building falls under, the menus of raw materials and finished goods that appear for them to select from are populated with materials that relate to the selected category. The program then calculates the emissions of the raw materials and the finished goods as contents of the production floor, raw materials storage and finished goods storage.

The main difference in the use of categories between the warehouse and industrial models is that in the industrial model, we placed the category selection in the beginning of the user input and it changes the lists of materials in the following steps. As one can see in the following screenshot (Figure 14), the first information asked from the user is the area of the industrial building, the area burned and the category of industry.

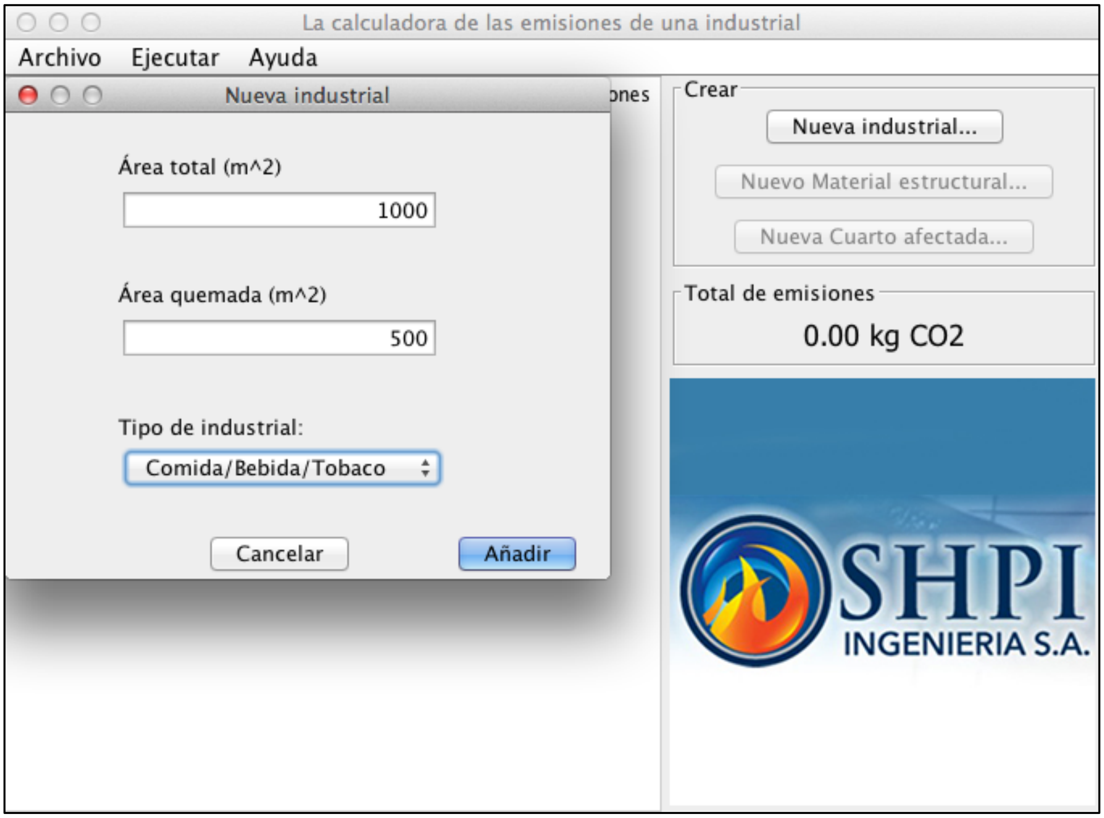

Figure 14: First Input for Industrial Model

When the user selects the category of the industrial building and then is called to input contents of the production floor, raw material storage and finished goods storage, the lists of options are different for each category. We decided to follow this sequence of user input, with selecting the category in the beginning, to make the material selection easier. The user doesn't have to go through long lists of raw materials that would never be used in the category they selected.

The types of input in the industrial model are broken down to input about structure ("Nuevo material estructural") and input on the different types of rooms. There is no shelving unit input, unlike the warehouse model, since from our physical inspections at industrial buildings we noticed that the finished good storage varies from one factory to the other.

4.3.2.2 Industrial Building Structure Emissions

The structure of industrial buildings is similar to the structure of warehouse, according to our interviews with Ing. Ramos and Ing. Solarte, as well as stated in the Treasury Manual. The use of polystyrene is less frequent in industrial buildings than warehouses. We confirmed that the two factories we visited did not have polystyrene insulation. However, we decided to keep it in the selection menu for the industrial building structure. Since we have the information for all the types of polystyrene and there is a possibility of it being used in industrial buildings, we kept it as part of the material selection for the structure of an industrial building.

The user input and calculations for emissions from the industrial building structure are the same as the warehouse structure emissions ones. Refer to section 4.3.1.1 for the detailed explanation of calculating structure emissions.

4.3.2.3 Calculating Content Emissions for Factories

The majority of industrial buildings in Costa Rica are factories, as seen in the CICR database. From our physical inspections of two factories, we collected information on the type of contents present in factories as well their layout. In this section we present how we used the information to make meaningful calculations for the contents of the industrial building.

The layout of a factory in terms of secondary rooms is similar to the warehouse. The only addition is the control rooms that we encountered in all factories. As the staff of the factories explained to us each time, those are the rooms where they use computers to follow the processes and inventories of materials online. In terms of content, the control rooms are no different from an office with many computers, therefore in the application they would be input as offices with a greater number of computers and desks. We observed two control rooms. We counted the desks to be 5 in one and 7 in the other, and each desk had one computer on it.

The biggest sources of CO_2 emissions in the factories are the fuel tanks that provide energy to their operations. In one of the factories we visited, there were tanks that held up to 140000 liters of fuel. Our guides in the two factories gave us the sizes of the tanks used on the site. Table 4 summarizes the types of fuel we encountered during our physical inspections in different industrial buildings, as well as their emission factors.

Table 4: Industrial Building Energy Sources

Type of Fuel	Emission factor (kg CO_2/gallon)
Diesel	10.21
Biodiesel	4.08
Gasoline	3.3
LPG (Liquid Petroleum Gas)	5.66
Bunker Fuel (Bunker Crude)	11.27

The fuels were all stored in large tanks outside the building. We decided that the most effective way to ask the user for information on the fuels is to add tanks as rooms, and request the user to input the volume and type of fuel. Then the program retrieves the emission factor of the fuel and calculates the emission if the tank was to burn. The screen below (Figure 15) shows the fuel tank selection process in the application.

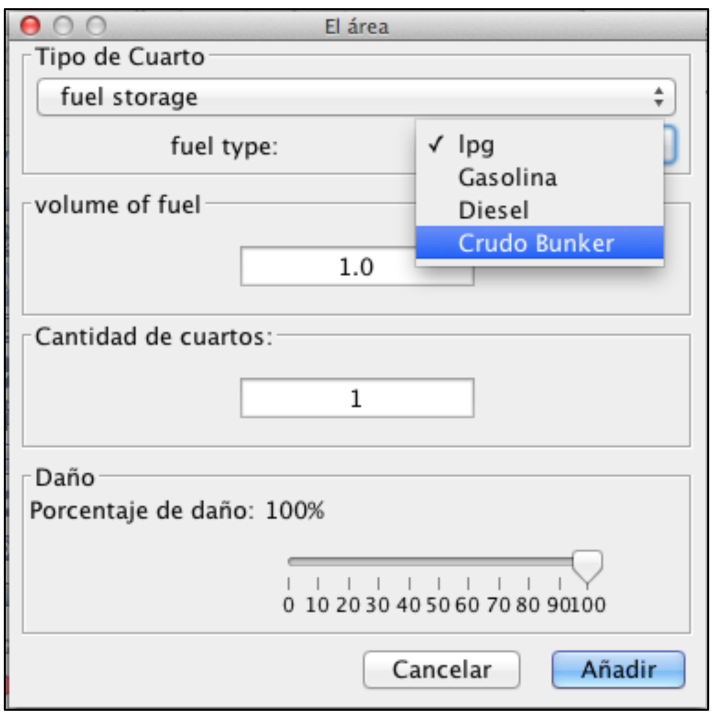

Figure 15: Fuel Tank Selection

We included the percentage damage selection, although fuels are highly flammable, so it is expected that if affected, the whole tank will burn. The percentage is preset to 100% but if for some reason the fire is put out fast enough so that not the whole tank burns, the user may select another percentage.

The model takes the input of the volume and the type of fuel and calculates the emissions from the combustion of the fuel. The emission factors for the fuels are an exception since they are measured in mass of CO_2 per gallon. The model multiplies the volume of the fuel to the emission factor to find the overall emission. For example, if a 100000 gallon tank of gasoline (emission factor: 3.3) burns down, there will be 330000 kg CO_2 emitted (330 metric tons).

The second biggest source of CO_2 emissions in case of an industrial fire is expected to come from the finished good storage. The reason behind this assumption is that in the factories we inspected, the finished goods were stored on either shelving units, similar to the warehouse, or stacked on wooden pallets. The bottling factory we visited, for example, used a sandwich stack of two pallets to store finished bottles (2000 bottles per unit). The large amount of wood and finished products increases the possible CO_2 emissions in event of a fire. The tire factory we inspected, on the other hand, used metal shelving almost exclusively. In the application, the user can choose the type of storage appropriate to the specific factory from a drop down menu, whose options are populated with the various types of storage we encountered in our inspections.

The largest room in the factories we visited was the production floor. In terms of contents, though, the only materials we took into consideration to calculate the emissions of the production floor were the raw materials and finished goods currently in use. At the suggestion of one of the engineers in the bottling factory we visited, we decided not to include the machinery in our calculations. He informed us that the machinery would not have a significant amount of emissions, since it is made of iron and aluminum, both pure metals that do not have emission factors. Due to this suggestion, and after cross-checking with other personnel in the factories we visited, we looked for an analysis of the components of industrial building machinery to make a decision on whether to include it in the calculation. The two main sources we looked at were two machinery vendors and distributors, Indiamart and Made-in-China. Some types of machinery we encountered were leather machinery, food packaging machinery and agricultural machinery. The only products for which we found component information, though, were stainless steel machine parts. We decided to not include machinery in the end of our research since there is a very wide variety of machinery, that would make it very hard to input information. Also, the user would most likely not know the material that the machines were made of. Making the assumption that the machines are made of metals with low or no emission factor is the easiest way to go about this issue, and also maintains a high level of accuracy. For the reasons stated above, we only calculate emissions of raw materials and finished goods found on the production floor during the fire.

Based on the categories of industries, we created lists of raw materials and finished goods. We understand that our list is limited to our own physical inspections and research. For this reason, the user has the choice of entering their own custom raw materials and finished products along with their emission factor and mass. We give the alternative of providing the volume and density in case they do not know the mass. For liquids this method of adding information is more efficient since liquids are usually measured in liters and their density is easy to find if it is not listed within the application.

The screenshot below (Figure 16) summarizes the input of raw materials and finished goods in the production floor. The model takes in the information about the material, retrieves the emission factor from the materials database multiplies it by the mass input by the user according to Equation 1.

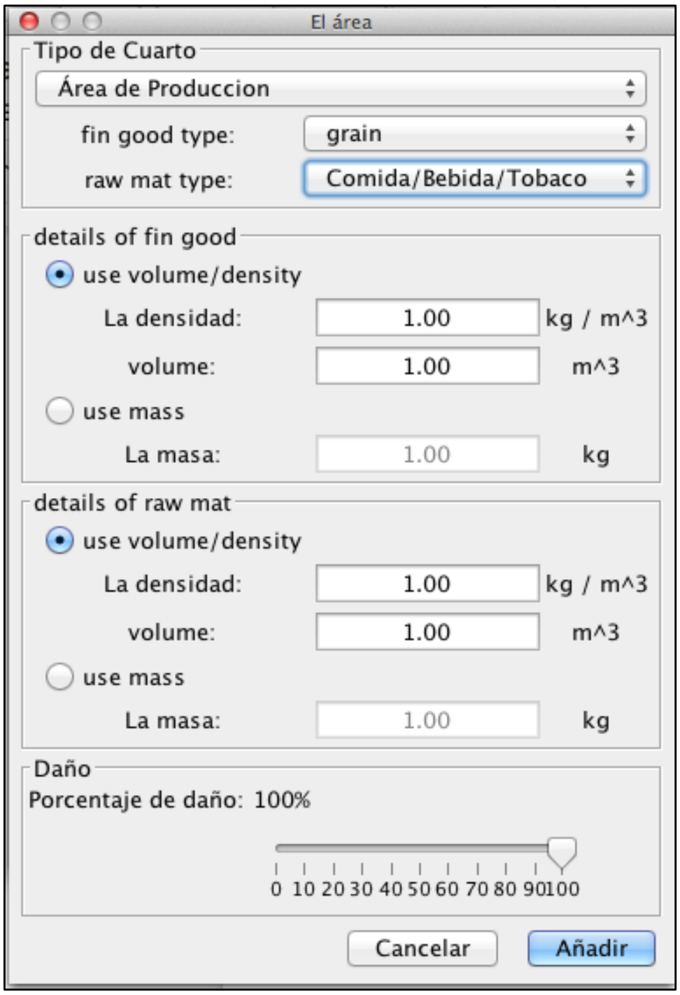

Figure 16: Selecting Raw Materials and Finished Goods

The raw materials were stored in silos in the factories we visited. Raw material storage is another input in our model. For this reason, we investigated whether factories have an inventory of raw materials. An accurate inventory would mean that the mass of raw material stored in the factory at any time is known. The management of the industrial buildings that we visited all had an inventory of the mass of those raw materials at any given day. During our visit at the bottling factory, the engineer that gave us a tour showed us those databases and also gave us a list of the raw materials they use for this industry. The materials and their emission factors can be found in Table 5.

Table 5: Raw Materials List Example

Raw Material	Emission Factor (kg CO_2 / kg)[1]
Limestone	0.44
Dolomite	0.48
Soda Ash	0.41
Sand	0.95
Recycled glass	0.06

In the case of the bottling factory, the user would have to input the type of raw material and its mass (or volume and density), based on their inventory. In the case of raw materials, factory personnel often measure amount by the container it is stored in, therefore by volume. For this reason, the raw material storage input can be in the form of volume and density, similarly to the production floor input. Then the model would calculate the emissions using the emission factor and mass (Equation 1). For example, if the bottling factory had 5 tons of limestone in a silo that was burned, the emissions would be calculated by multiplying its mass by its emission factor, 0.44. As a result, 2.2 tons of CO_2 would be emitted.

4.4 Improving User Friendliness

We designed the application to guide the user step by step to input the type of building, building area, affected area, type of room, area of room, and contents. The user selects the input from a drop-down menu or describes the areas using numbers. The application was designed to be very easy to use, without complicated instructions and with a pleasantly simple interface. Its user friendliness also contributes to the accuracy of the results. If the user were to inaccurately input data, for example, a letter in the total area or a room that exceeded the overall structure area, the application will display an error notification to stop them from inputting inaccurate information.

The user must input what category the building belongs to as well as details about each room of the building. All this information is essential for the accuracy of the model. However, we understand that it is an overwhelming amount of information to be aware of and to input, and we are prepared for the possibility that the user might not know all the details the application asks for. Our innovative approach of overcoming the obstacle of unknown information was to introduce default options for each input field that is required. This way, no information is omitted.

When users run the application, they have to enter each room of the building from a drop-down menu of available room types. Then, they have to select all the contents of each room. In this list of possible room contents, there is a default loading option for each room. This option is very useful, especially in case the user does not know the contents of the room in question. The screenshot below (Figure 18) demonstrates the default option and how it appears in the application. In this specific example, we are in the warehouse model, selecting the contents of an office. If the user does not know what was in the room, all they need to do is select the default room loading.

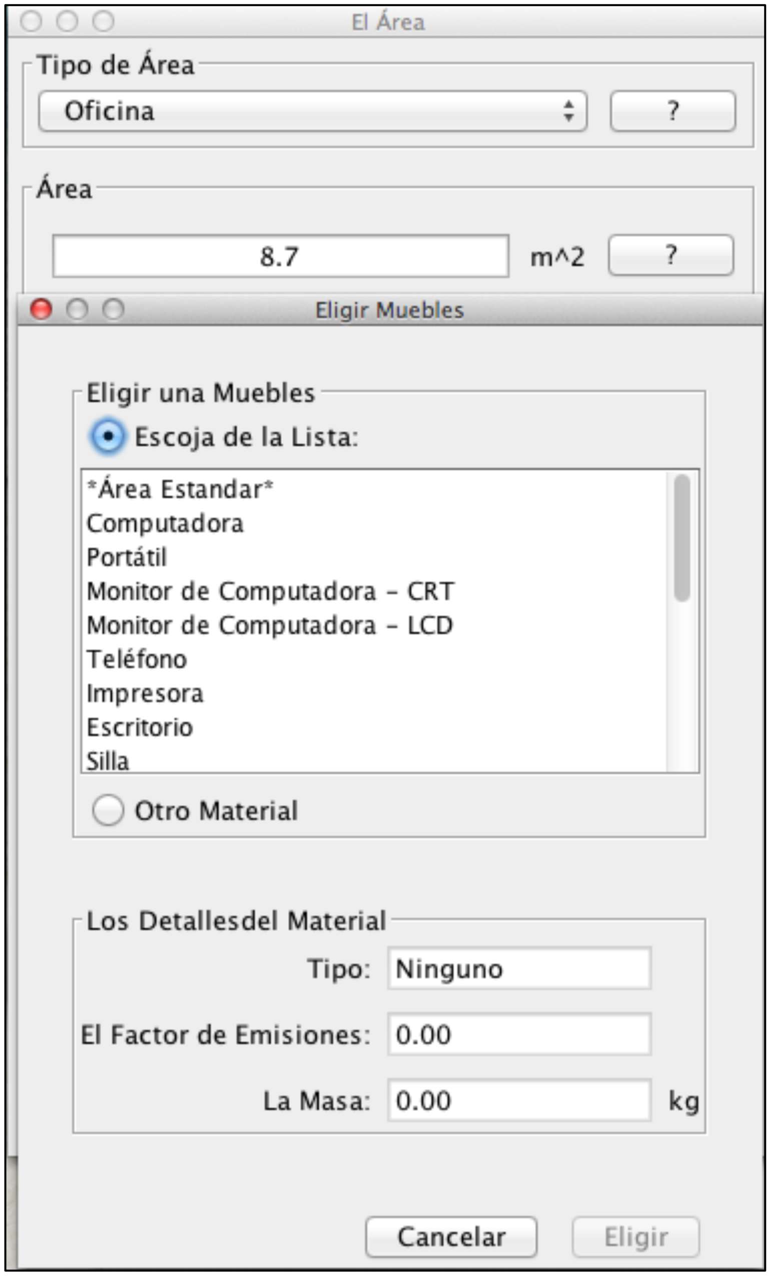

Figure 17: Default Room Loading Option

The default room loading (*Área Estandar*) was calculated by averaging the contents of all the rooms from the warehouses and industrial buildings we inspected that fall within the same type (office, break room, bathroom etc.). Additionally, when adding a new secondary room, the area is preset to the average area we calculated for this specific type of room. This addition makes sure that there is a preset value to use in the calculation in case the user does not know or forgets to enter a value for area. The calculations behind the default loading for office, cubicles, break area, bathroom and conference room can be found in Appendix I.

As an example, when calculating the default office loading, we averaged all the emission factors of all the contents of the offices we inspected. We divided that with the average of all the areas of offices (8.7 m^2). The end result was the CO_2 emissions per unit area of each type of room. The model uses the emissions per area and multiplies it by the area of the room that the user inputs to find the content emissions of that room.

Another feature we added to the application to improve user friendliness were help boxes. These help boxes are located throughout the app to aid the user during the calculation for carbon emissions of a specific building type. They help the user understand what the app is asking for by giving a detailed explanation sometimes accompanied by a photo. This increases the accuracy of the app as well since there will be no misunderstanding as to what the app is asking for. Figure 18 shows what the user would see if they were to click on the help box when filling out the height of the shelving unit.

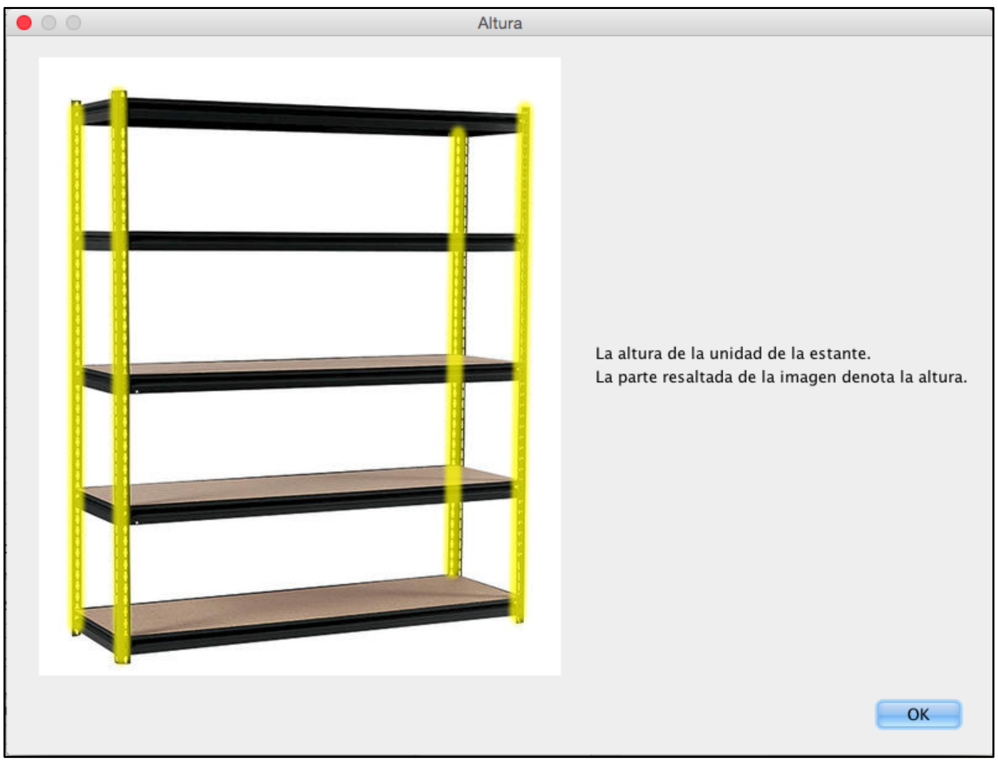

Figure 18: Shelving Unit Height Help Box

In Figure 18, the part of the shelf where height would be measured is highlighted. There is also a short description that further explains what is being asked for and what the picture depicts. Another example can be seen when the user clicks on the help box when inputting the percentage of the shelf that was burned. This can be seen below in Figure 19.

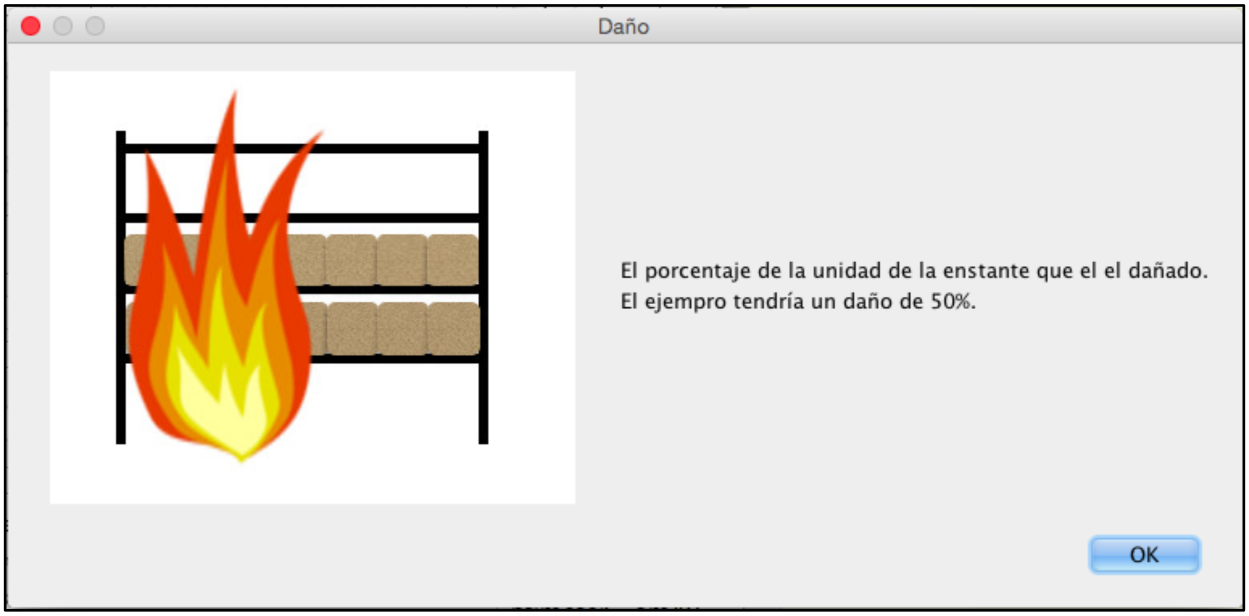

Figure 19: Percent of Shelf Burned Help Box

In Figure 19, there is an image that shows fire burning a shelf. It can be seen in the image that the fire is only burning half of the shelf. In the description to the right of this picture, it is explained that the percentage of the shelf that was burned would be 50%, since in the picture only half the shelf is being burned.

This concludes our model development. Once we created the warehouse and industrial model, we needed to verify their results. We used the detailed inputs of the application to collect information on the structures. For each input, we carefully applied the given values into the calculations, to ensure the greatest accuracy possible. The next section goes into detail of how we verified this accuracy.

5. Model Evaluation

Our goal throughout this project was to improve the accuracy and user friendliness of the warehouse and industrial model. After applying our methods, collecting data and developing the new, updated models, we had to verify that the models have the desirable results. In this section we present the results of evaluating and verifying the improvement of our models in terms of accuracy and user friendliness.

5.1 Verifying Model Accuracy

After looking at models from different countries, we realized that all the models were geared towards the residential model. The previous WPI group had used a model developed in Sweden that only calculated emissions from fires in residencies. After looking at the Bomberos report from 2013, we concluded that most fires happen in residential buildings. This explains the high concentration of gas emission tracking models that only pertain to residential buildings. With that being said, the Environmental Protection Agency (EPA) has created a general model that applies to all building types but lacks specificity. This is the model that we chose to compare our model and the previous model with.

We used an example warehouse of 100 m^2 that stored food products and entered this information in the three models: our new, updated warehouse model, the EPA model and the previous warehouse model. Our model is the one that required the most input, and for this reason we conclude that there is information that the other two models omit. We compared the three final numbers for kg of CO_2 emissions from the structural fire in this warehouse.

As we ran all three models to see which one would produce the most accurate result, the one we started with was the previous warehouse model. The only input this model required was the total area, burned area and purpose of the warehouse, as well as its primary structural material. For consistency, we chose concrete for the structure of the warehouse in all three cases. The screenshot of the previous model and the result is found below (Figure 20):

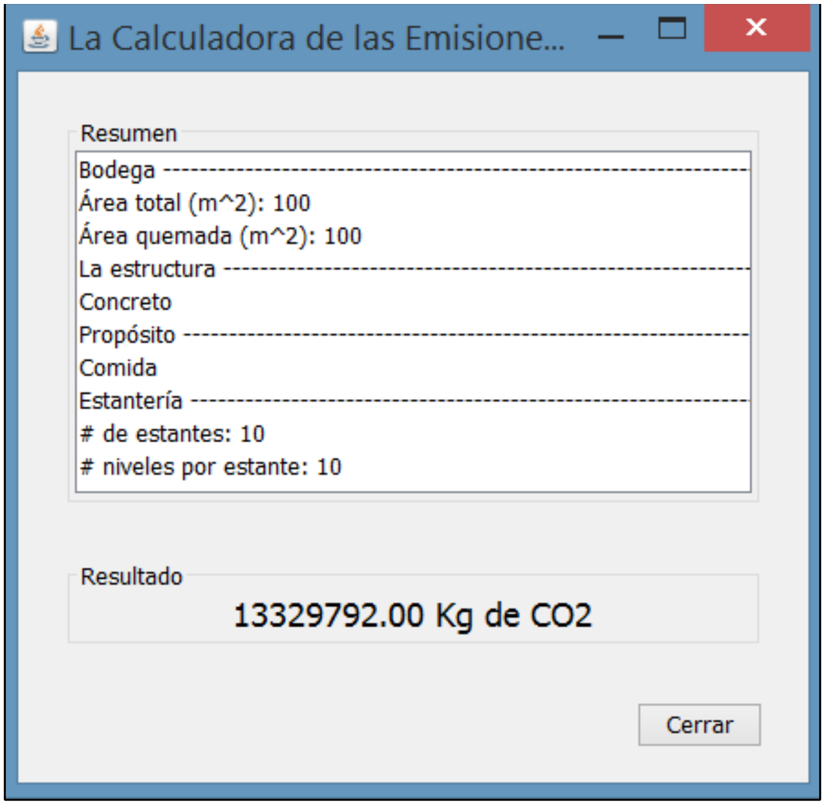

Figure 20: Testing the Accuracy of the Previous Warehouse Model

The warehouse for this example had 10 shelving units and 10 shelves per shelving unit. There is a lot of material in this one warehouse, but the warehouse itself is not very large; it is about one tenth the size of an average commercial warehouse. The end result, as one can see in the above figure, is a little over 13,000 metric tons of CO_2. With the total annual emissions from structural fires being 34,000 metric tons, this single fire accounts for almost 40% of the annual emissions.

The second model we ran was the EPA model. We used the same area and the emission factor for CO_2 to calculate the emissions for the same warehouse. The EPA model is just a set of equations that you can use to calculate carbon dioxide emissions. The average weight per m^2 for both content and structural material is needed in this equation; the model provides an average of 3.58 kg for content material and 39.38 kg for the structural material. The final result for this warehouse calculation was 21 tons of CO_2. The result is about 0.06% of the overall emissions, which is more realistic than the previous one, however appears to be too low.

Finally, we entered the same information in our own model, as seen in Figure 21. We added the same dimensions as the previous models. However, due to our extensive research on carbon emissions of food and how it is shelved, we had a more accurate average of food. We also inputted that the shelves were only 80% full and took up only 30% of the height in each shelf which is typical for a store, something we learned from doing our inspections.

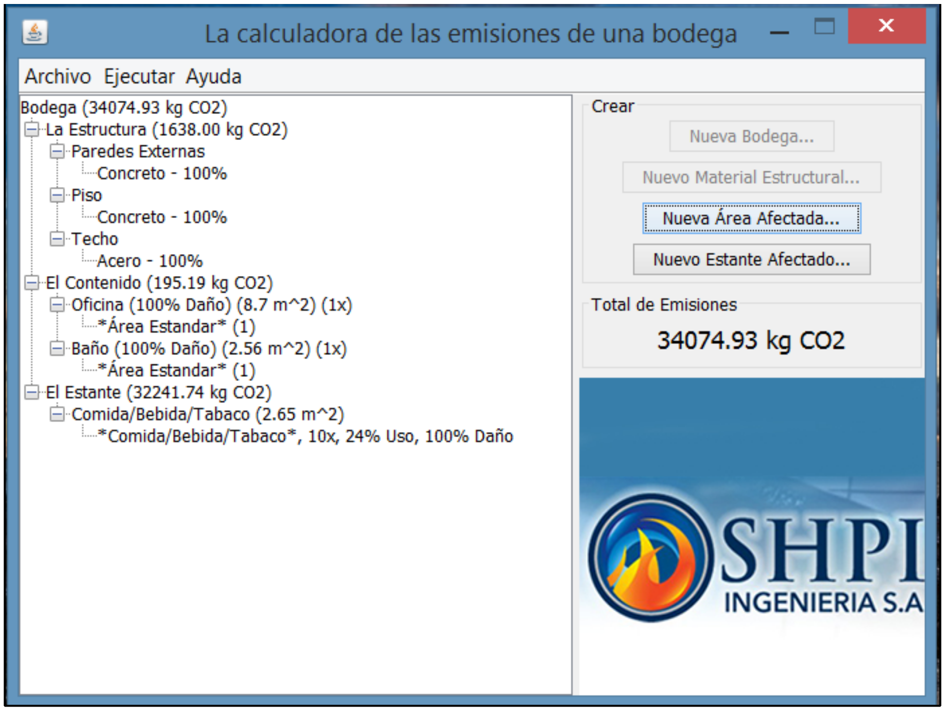

Figure 21: Testing the Accuracy of the Updated Warehouse Model

The end result for the warehouse was 34 tons of CO_2. That number is also realistic, according to the calculations of the overall CO_2 emissions of Costa Rica from structural fires. It comprises of about 0.1% of the overall emissions.

The amount of carbon dioxide emissions per year from 2009 to 2013 was approximately 34,000 metric tons as calculated by last years group. This calculation was made by the average carbon content in a residential building multiplied by the average number of fires in those years. In 2013, the Bomberos reported approximately 1000 structural fires. By multiplying the number of fires by the average amount we received from each model, our model was proven the most accurate.

The previous year's model turned out to be approximately 130,000 metric tons which far exceeds the yearly annual emissions from structural fires. The second model, the EPA model, turned out to be approximately 21,000 metric tons, which is under the average emissions. Our model approximated 34,000 metric tons, being right on the average for total emissions.

The reason the other models are off is because of their lack of specific data. Our models are the first of their kind that provides a specific database of materials as well as structural material that matches those of actual structures. Our model does not take the weight of each square meter and multiply it by the total area to give us a rough estimate of emissions like the EPA model. Our models are the only ones that have the materials found in industrial and warehouse buildings, the different rooms in each, and the specified input dimensions in order to receive the accurate amount that was burned.

To verify the precision of the output, we calculated the potential emissions from an example scenario by hand. The same data used in the hand calculations was then input into the model. Using the two output numbers of total carbon dioxide emissions, we gaged the accuracy of the warehouse model at 99.9998%, or 0.0002% error. The minute amount of error in the value output by the model is only due to the model truncating the value to two decimal places, for the sake of readability by the user. The calculations used to gage the accuracy of the model can be found in Appendix J. This extraordinary amount of precision confirms that the equations used within then application are functioning correctly.

5.2 Feedback Session Results

After the completion of our model, we held a feedback session in the form of a focus group, as discussed section 3.4 of the Methodology. The participants of this focus group were 3 SHPI personnel and 2 Bomberos personnel that had not been exposed to the application yet. The results of the feedback session were very successful based on the overall score and commentary. Our first two questions were ratings, on a scale from 0 to 10, asking the user about the aesthetics of the application and then about how easily they were able to navigate through the application. From the chart below (Figure 22) you can see our mean, median, and mode scores.

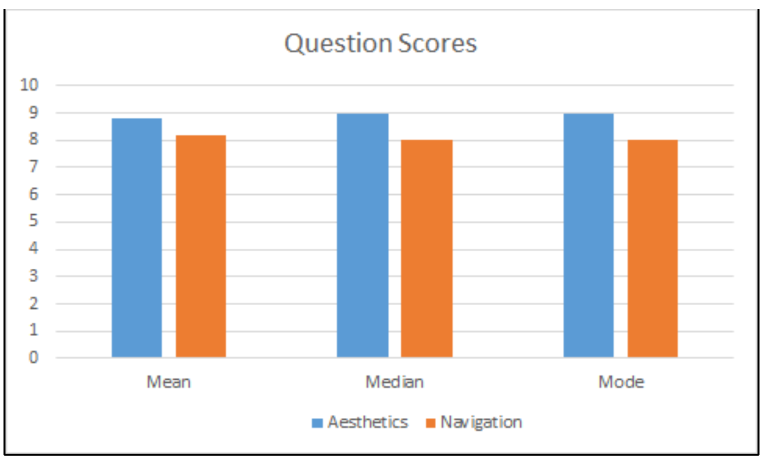

Figure 22: Feedback Session Results

Based off the above chart, our average score for the aesthetics was an **8.8** while our score for easiness to use was a **8.2.** These are great numbers to have from people who are using the application for the first time. With our provided code commentary and written instructions, that we will explain later, the user should have no trouble navigating through our application. Our median and mode show that most users felt that our application was good and easy. 80% of users gave a 9 or better on our aesthetics while our navigation received a 80% of a 8 or better.

Despite a couple bugs in the code, which are now fixed, overall the application received great results. These mishaps included the PDF generator producing duplicate entries of shelving units and the application not fitting on the computer screen, due to resolution issues. For the first problem, the code was not properly catching the errors from the users and was adding duplicate shelves to the final report that it shouldn't have. The second problem occurred on a computer-to-computer basis, and was to due to low resolution on some screens, causing the application to appear larger than normal. Both problems have been addressed and our models are working at optimal level.

Based off of our focus group questions, the main concern that was voiced was that several people needed a little help getting started. They were curious which section they were suppose to begin with. Other concerns were related to the fact that the application only allows the user to fill out data in the order it was listed. We received several comments asking us to provide a small tutorial, which would make the application easier to understand for first time users. The tutorial would be specifically helpful in explaining the use of average room loadings.

5.3 Creating Tutorials and Instructions

We created new models using up to date information that we collected through our research, physical inspections and interview. However, the emission factors, materials, products and structures of the buildings will not be constant forever. Already, we have noticed a change in structure materials, with the addition of polystyrene as a common modern construction material. The possibility of new materials and new types of products should not create problems with using our application. Our goal was to create an application that can be modified to include any possible future modifications. As we are leaving this application to SHPI to use in the future, we had also leave them with instructions on how to update it.

We came up with a way to accommodate change in our application. This was through including non-executable comments in the code that describe how each component operates, and what that particular component codes for. This way, someone with little training or knowledge of coding can orient themselves to the program, and make modifications where needed. An example of some non-executable comments can be found below. These comments explain, step by step, the calculations made for the emissions of two types of shelves bases that could be used in the model (pallet base and wood base).

Shelf.java

```java
        }

        if (shelfBaseType.equals(ShelfBaseType.NONE)) {
            shelfBaseEmissions = 0;
        } else if (shelfBaseType.equals(ShelfBaseType.PALLET)) {
            /**
             * Standard ISO pallet size = 1.016m x 1.219m
             * Average mass for ISO standard pallet = 19.18525 kg
             * Emissions factor for wood = 1.5
             *
             * Calculations multiply the average mass for a pallet
             * by the maximum number of whole pallets that could fit on the shelf,
             * and then by the number of levels of shelving.
             */
            int numPallet = (int) (shelfBaseArea / (1.016 * 1.219));
            shelfBaseEmissions = numPallet * shelfLevels * 19.18525 * 1.5;
        } else if (shelfBaseType.equals(ShelfBaseType.WOOD_BASE)) {
            /**
             * Area of wood on shelf base = shelfBaseArea
             *
             * Most common 2x6 material is Douglass Fir, Yellow Pine, or Spruce
             * Density of Spruce = 450 kg/m^3
             * Density of Yellow Pine = 420 kg/m^3
             * Density of Douglass Fir = 530 kg/m^3
             * AVG Density = 466.67 kg/m^3
             * Emissions factor for wood = 1.5
             *
             * Height of shelf base = thickness of 2x6 = 1.5" = 0.0381m
             */
            shelfBaseEmissions = shelfBaseArea * 0.0381 * 466.67 * 1.5;
        }

        /**
```

Figure 23: Non-Executable Comments Example

6. Conclusions and Recommendations

The deliverable of this project is two updated, functional models that calculate CO_2 emissions from structural fires in warehouses and industrial buildings. Those models are incorporated in an application that includes the residential model developed by last year's group. It is a tool that is ready to be used by SHPI Ingeniería and the organizations listed in the Background section (*Bomberos*, *Carbono Neutral* and *Estado de la Nación*).

Based on the results of section 5.1 of Model Evaluation, the results that the warehouse and industrial models give are accurate and precise. Our detailed approach of having the user input many types of information about structure and contents separately worked to our favor since our models exceeds the other two in accuracy. Our primary goal, that was to improve last year's model, was met with success. The results of the hand calculations test also show that the application uses the calculations correctly.

Our choice of using the equation from last year (equation 1 from section 4) was correct, as the high accuracy of our models shows. We can conclude that this equation is a good, accurate calculation to be used for CO_2 emissions estimation. Our increased accuracy while using this equation also increases the reliability of the residential model that is based on the same mathematical formula.

Our models are also successful in terms of user friendliness. The results we received from our feedback session support this conclusion. We worked hard to create the default options so that the user would not be overwhelmed by the amount of detail. Also, with the default options, the accuracy was still met even with lack of information from the user.

6.1 Future Recommendations

By completing the warehouse and industrial models, we have helped SHPI come closer to achieving their goal of being able to track emissions from all types of structural fires. Our vision is that these models will continue to be improved upon and for their use to be expanded further beyond educational purposes. Some future recommendations we have are the following:

Continue updating the created warehouse and industrial models with additional materials based on the instructions accompanying these models.

Continuous improvement is important in keeping these models accurate. We understand that overtime, new materials may arise and building codes may change. A recent example of this was the introduction of polystyrene into warehouse and industrial structures as insulation. This was a fairly new material as it was not listed in data published by the treasury about structural materials in Costa Rica. For this reason, SHPI personnel need to be able to edit the application accordingly. They may need to change emissions factors as well as add new materials to the databases within the application. To help SHPI personnel make these edits, we provided them with written instructions as well as included non-executable comments throughout the code. The written instructions advise SHPI personnel how to edit the code. This included step-by-step procedures on how to edit certain aspects of the code as well as where to find them within the code. Non-executable comments are sentences within the code explaining what the code does in non-technical terms. This will help non-programmers further understand what the code means and how it works. With these provided materials, we believe that SHPI will be able to make these edits with ease when needed to in the future.

Begin research into other environmentally harmful emissions from structural fires (CO, Particular Matter, VOCs etc.) and expand current models to include these emissions.

Our second recommendation was a byproduct of our research on emission factors. Carbon dioxide is the most well known harmful emission, but there are other emissions that also affect health and the environment that we believe should be looked into. These emissions are carbon monoxide, particulate matter (PM), and volatile organic compounds (VOCs). Carbon monoxide is a highly poisonous substance that comes from the incomplete burning of gas and liquid petroleum gas (Carbon Monoxide Questions and Answers. (n.d.)). Particulate matter is a complex mixture of extremely small particles and liquid droplets. When inhaled, they affect the heart and the lungs and can cause serious health issues (Particulate Matter. (n.d.)). Volatile organic compounds are produced from vehicle emissions and chemical solvents. A high content of this emission produces smog, which has both health and environmental impacts (An Introduction to Indoor Air Quality: Volatile Organic Compounds (VOCs). (n.d.)). Being able to track these emissions is important in protecting the health of fire fighters. Since they are often exposed to these emissions first hand, knowing how much is being emitted and the dangers that come from that emission level would help them take appropriate safety precautions.

We believe that this is would be an easy feature to add as long as information on these harmful emissions is available. Through research for carbon dioxide emission factors, we also came across carbon monoxide emission factors. More research is needed on emission factors for particulate matter and volatile organic compounds. If the emissions factors are found, this is the only feature that will need to be changed in the calculation in order to calculate these different emissions. Therefore, only minor edits to the code need to be made.

Use the results of the application towards mitigating structural fire CO_2 emissions and achieving carbon neutrality.

Currently, the results from our application are only being used for educational purposes. We hope that in the future, the results from our application will also be used to help mitigate carbon dioxide from the atmosphere emitted by structural fires. Since Costa Rica wants to become carbon neutral by 2021, all emissions need to be monitored and mitigated. Our application is easy to use and produces and accurate result. We recommend that information produced by this application be used in the carbon offsetting process. We provided SHPI Ingeniería with this model to share with the sectors that work on carbon neutrality and carbon offsetting. We hope that in the future this tool can help Costa Rica achieve and maintain its goal of carbon neutrality.

Implement a similar approach to create a Hospital Model with improved accuracy.

Although we did not have time to complete the hospital model, it is still a very important aspect in helping SHPI reach their goal of having methods to track the emissions from all types of structural fires. We have some ideas and recommendations for making a successful hospital model in the future. Our first recommendation is that the room by room approach is used and that emissions are broken down contents vs. structure. These methods have been successful for the residential, warehouse, and industrial model, so we believe it would also be successful for the hospital mode. Through research, we also found many similarities between hospital rooms and residential rooms. Therefore, information from the residential model should be used to help populate the databases within the hospital model. Throughout our time in Costa Rica, we found physical inspections to be a useful tool in order to collect information about the contents and secondary rooms of different types of structures. Doing physical inspections of various types of hospitals will allow accurate data to be collected, which will therefore produce an accurate result.

Add a category for power plants in the Industrial model.

Power plants are a category of Costa Rica's industrial buildings. We chose to omit this option from our industrial model while in Costa Rica due to a lack of time and the minimal emissions most power plants emit when burned. The majority of power plants are hydroelectric, therefore the only emissions that come from these power plants are from the structure and machinery. These two factors often emit little to no carbon when burned. Although these facts make the power plant category seem unimportant, it is still necessary to account for them within the industrial building type in order to have a complete model.

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Appendix A - Questions About Previous Models

1. What aspects of the residential model do you like?
2. What makes the current warehouse, industrial, and hospital models inaccurate?
3. What would you like us to add to the warehouse model to make it more successful?
4. What would you like us to add to the industrial model to make it more successful?
5. What would you like us to add to the hospital model to make it more successful?

Appendix B - Interview Questions for Civil Engineers

We will ask you a series of questions on the structural materials of three different types of buildings in Costa Rica. The information we need is about buildings in Costa Rica and are not specific to your company.

QUESTIONS

1. What of the three following buildings do you have more experience with?
   i. hospital
   ii. industrial
   iii. warehouse
2. What is the primary structural material of the buildings?
3. What percentage of this material defines it as primary?
4. What other materials are there in the structure besides the primary one?
5. What are their percentages?
6. Is there a difference in building structure within subcategories of this type of building?
   i. hospital: rural, urban, assisted living
   ii. warehouse: electronics/appliances, food, cloth/wood, chemicals
   iii. industrial: powerplants, factories
7. Will there be a change in materials used in any of those structures in the future?

Appendix C - Data Sheet for Physical Inspections

	Emissions Tracking Form	Costa Rica IQP 2015	
Building:			
Structure Class:	Hospital	Industrial	Warehouse
Subcategory:			Other
If 'Other', explain:			
Primary Structure Material		Primary Content Material / Use:	
Area of Structure:			
Other Dimensions / Measurements:			
For Warehouse:			
# of Shelves:		Shelf Size (LxWxH):	

Appendix D - Feedback Session Survey

La calculadora de emisiones de incendios estructurales

Stella Banou, Devin Duarte, Kyle Fortin, Taylor Llodra

Gracias por su participación. Su opinión es muy apreciada.

1. De 1 a 10, ¿cómo Usted califica la estética de la aplicación?

   1 2 3 4 5 6 7 8 9 10

2. De 1 a 10, ¿cómo Usted califica la facilidad de navegar esta aplicación?

   1 2 3 4 5 6 7 8 9 10

3. Basándose en su experiencia profesional, ¿diría que el resultado es realístico?

4. ¿Hay una característica específica que Usted cambiaría en esta aplicación en cuanto a la estética?

5. ¿Hay una característica específica que cambiaría en esta aplicación por hacerla más fácil de usar?

Appendix E - Sample of Material Database

Material	Weight kg	CO2 (kg)	EF					EF
E-WASTE MARERIAL					**FOOD PRODUCTS**			EF
Desktop Computer	9.9	17.8	1.798		Bread (loaf)	0.6	0.38	0.633333:
Laptop Computer	3.5	6.3	1.800		Gallon Bottle/Carton	0.15	0.9	6
CRT Screen	14.1	25.4	1.801		Fruit/Vegetables 50lb	22.7	11.4	0.502202(
LCD Screen	4.7	8.46	1.800		Glass Bottle	0.23	0.01	0.043478:
Mouse	0.05	0.09	1.800		Glass Plate (78 plates)	78	3.9	0.05
Keyboard	1	1.8	1.800		Meat	0.453	0.2	0.441501:
Printer	6.5	11.7	1.800		Carbonated Drinks	1	0.08	0.08
Mobile Phone	0.1	0.18	1.800		12oz beer	0.192	0.03	0.15625
Mobile Phone charge	0.1	0.18	1.800		Bottle of wine	1.36	0.54	0.397058:
eo Recorder/ DVD Pla	5	9	1.800		Hard Liquor	1.36	1.8	1.323529‹
Hi-Fi system	10	18	1.800		Milk gallon	3.9	0.2	0.051282(
Radio	2	3.6	1.800		Cheese	0.25		0
Telephone	1	1.8	1.800		Canned Goods	0.4	0.1	0.25
Vacuum Cleaner	8	14.4	1.800		Yogurt			
Iron	1	0	0.000		Rice 1kg bag	1	0.54	0.54
Kettle	1	0.2	0.200		Potatoes	1	0.17	0.17
Toaster	1	0	0.000		plastic bread bag	0.01	0.06	6
Mixer	1	0.2	0.200		frozen food bag	0.45	2.7	6
Hair Dryer	1	0.2	0.200		carbdboard box	0.17	0.26	1.529411:
Electric Drill	2	0.4	0.200		butter			

Appendix F - Warehouse Shelf Dimensions

	Warehouse Shelving Unit Dimensions				
	Length	Width	Height		
Single Product Warehouse A	2.87	1	4.6		
Single Product Warehouse B	2.87	0.92	4.33		
Commercial Warehouse A	2.87	0.9	4.32		
Commercial Warehouse B	2.9	0.86	4		
Average	2.88	0.92	4.31		

Appendix G - Shelving Unit Mass Calculation

Beams: 0.08 m x 0.08 m
Cross Sectional Area of the Beams = 0.00025 m^2
Height: 4.31 m
Width: 0.92 m
Length: 2.88
Density of Steel = 7850 kg/m^3
Number of shelf levels: 5
Linear density (kg of steel/m of beam):
0.00025* 7850 = 1.974 kg/m

Vertical Beams:
This number multiplied by the height of the beams gives the mass of steel in each beam. *4 for all beams
1.974*4.31 = 8.5 kg steel

Horizontal width beams:
Mass of steel: 1.974* 0.92 *2 *5 = 18.16 kg

Horizontal length beams:
Mass of steel: 1.974*2.88*2*5 = 56.85 kg
Total mass of steel = 83.51
Emissions from skeleton = 83.51*0.017 = 0.977 kg CO_2

We need to add the wooden part of the shelves. For this example, we use wooden pallets (1 m x 1.2 m). Mass of 19.19 kg
First, we need to find how many pallets fit in the base area of the shelf.
Base area = (2.88 - 2*0.08)*(0.92 - 2*0.08) = 2.07 m^2
# of pallets = 2.07/ 1.2 = 1.72 which rounds up to 2 pallets
Mass of wood = 2*19.19*5 = 191.9 kg
Emissions from wood= 191.9*1.5 = 287.85 kg CO_2

Total emissions for shelving unit = 287.85 + 0.977 = 288.8 kg CO_2

Appendix H - Shelving Unit Contents Calculation

We will use the dimensions of shelves from appendices B and C. For this example, we will calculate the emission factor for a shelving unit storing high density fiberboard (density = 920 kg/m^3, emission factor = 1.5)

First, we need to calculate the volume of material that fits in the shelving unit. This volume is the base area of the shelf times the height. We also need to subtract the wooden shelves volume

Total volume = 2.07*(4.31 - 5*0.08) = 8.09 m^3

Mass of fiberboard stored on that shelving unit if 100% full = 8.09 * 920 = 7446 kg of firewood

Assuming that the shelving unit is 70% full,

Emissions = 0.7*7446*1.5 = 7818 kg CO_2

Appendix I - Default Room Loading for Bathroom

Length	1.8	m		
Width	1.2	m		
Area	2.16	m^2		
Content	Quantity	Mass	EF	kg CO2
Toilet	1	30	0	0
Sink	1	20	0.00585	0.117
Cabinet	1	7	0.756	5.292
			TOTAL:	5.409
			PER AREA:	2.504

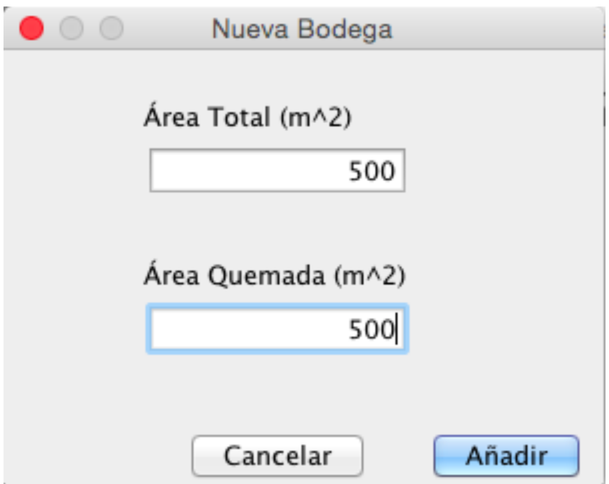
Appendix J - Calculations for Gaging Model Accuracy

The following calculations were used to gage the accuracy of the output of the warehouse model. The data was calculated by hand, and then input into the model to ensure that the numbers that the model output were sufficiently accurate.

Calculations:

Warehouse Total Area (A_T) = 500 m^2

Warehouse Burned Area (A_B) = 500 m^2



Input of Total Area and Burned Area

<u>**Structure Emissions:**</u>

External Walls:

Steel:

Thickness (t) = 0.00159 m

Length of Wall (L_w) = ($\sqrt{A_T}$) - t = 22.359089 m

Area of Wall (A_W) = L_w * t = 0.03555095 m^2

Height of Wall (h_W) = 6.71 m

Volume of Wall (V_W) = A_W * h_w = 0.2385469 m^3

Total Volume (V_T) = 4 V_W = 0.954188 m^3

Density of Steel (ρ_{steel}) = 7850 kg/m^3

Mass of Steel (m_{steel}) = ρ_{stee} * V_T = 7849.8263 kg

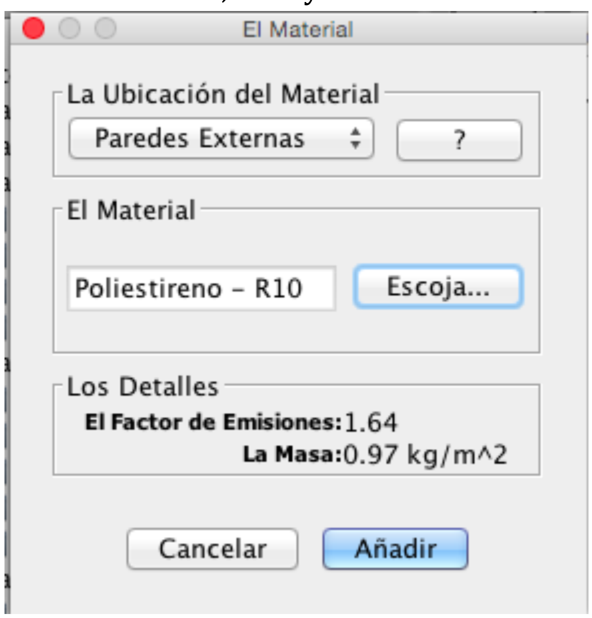
Surface Density of Steel (SD_{steel}) = m_{steel} / A_T = 14.9796526 kg / m^2

Emissions Factor of Steel (EF_{steel}) = 0.0117 kg CO_2 / kg

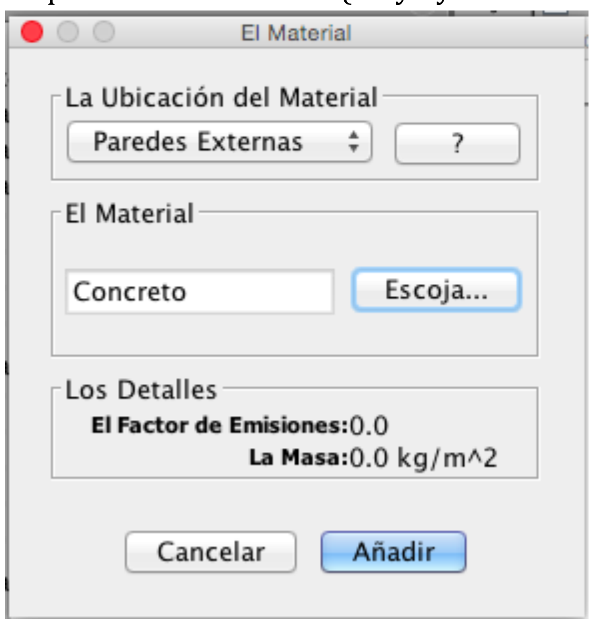
Emissions from Steel (E_{steel}) = m_{steel} * EF_{steel} = 87.630968 kg CO_2

Polystyrene (R-10 value):
Thickness (t) = 0.0508 m
Length of Wall (L_w) = ($\sqrt{A_T}$) - t = 22.309879 m
Area of Wall (A_W) = L_w * t = 1.133341 m^2
Height of Wall (h_W) = 6.71 m
Volume of Wall (V_W) = A_W * h_w = 7.604724 m^3
Total Volume (V_T) = 4 V_W = 30.418896 m^3
Density of PS (ρ_{PS}) = 16 kg/m^3
Mass of PS (m_{PS}) = ρ_{PS} * V_T = 486.702342 kg
Surface Density of PS (SD_{PS}) = m_{PS} / A_T = 0.973405 kg / m^2
Emissions Factor of PS (EF_{PS}) = 1.64 kg CO_2 / kg
Emissions from PS (E_{PS}) = SD_{PS} * A_B * EF_{PS} = 798.191841 kg CO_2

Concrete:
(As concrete has an emissions factor of 0.00, it may be excluded from calculations)



Model Inputs of External Wall (Polystyrene and Steel)



Model Input of External Wall (Concrete)

Roofing:

Steel:

Thickness (t) = 0.00159 m

Area of Roof (A_R) = A_T = 500 m^2

Volume of Roof (V_R) = A_R * t = 0.795 m^3

Density of Steel (ρ_{steel}) = 7850 kg/m^3

Mass of Steel (m_{steel}) = ρ_{steel} * V_R = 6240.75 kg

Surface Density of Steel (SD_{steel}) = m_{steel} / A_T = 12.4815 kg / m^2

Emissions Factor of Steel (EF_{steel}) = 0.0117 kg CO_2 / kg
Emissions from Steel (E_{steel}) = SD_{steel} * A_B * EF_{steel} = 73.016775 kg CO_2

Model Input of Roofing (Steel)

The concrete used in the roofing, as well as the floor, may be excluded, as it has an emissions factor of 0.00 kg CO_2 per kg of material.

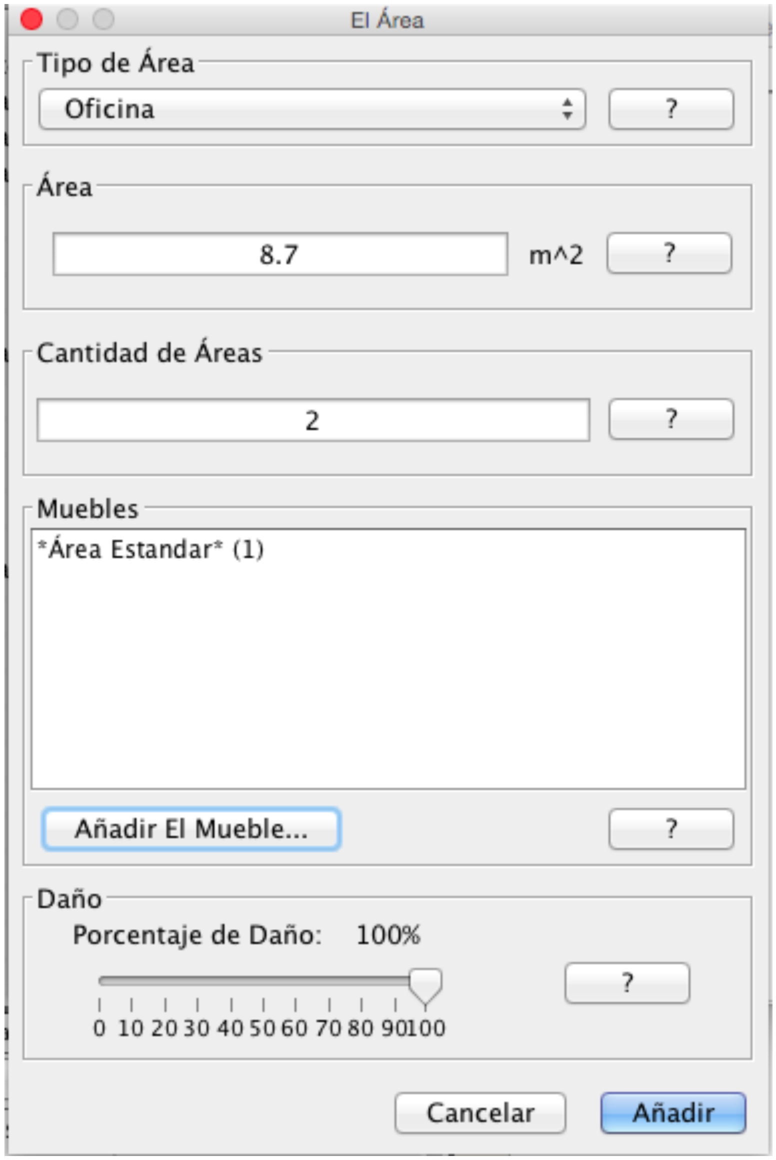
Total:

Total Structure Emissions = Emissions from Roofing + Emissions from External Walls = 958.839584 kg CO_2

<u>Content Emissions:</u>

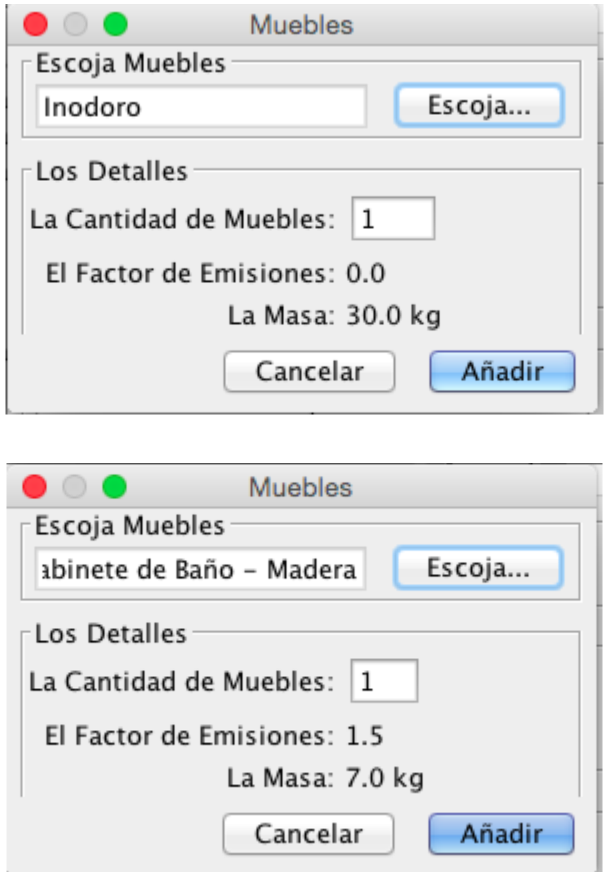
Office:

Area of Room (A_C) = 8.7 m^2
Content: *Default Room Loading* (21.699 kg CO_2 per m^2)
Quantity of Rooms (Q) = 2
Emissions from Contents (E_C) = A_C * 21.699 * Q = 377.5626



Model Input of Office

Bathroom:
Contents: 1x Toilet, 1x Wooden Bathroom Cabinet
Mass of Toilet (m_{toilet}) = 30.0 kg
Emissions Factor of Toilet (EF_{toilet}) = 0.0 kg CO_2 / kg
Emissions of Toilet (E_{toilet}) = m_{toilet} * EF_{toilet} = 0.00 kg CO_2
Mass of Cabinet (m_{cab}) = 7.0 kg
Emissions Factor of Cabinet (EF_{cab}) = 1.5 kg CO_2 / kg
Emissions of Cabinet (E_{cab}) = m_{cab} * EF_{cab} = 10.5 kg CO_2
Emissions from Content (E_C) =E_{toilet} +E_{cab} = 10.5 kg CO_2



Model Input of Bathroom Content

Total:

Total Emissions from Contents = 377.5626 + 10.5 = 388.0626 kg CO_2

<u>Shelving:</u>

Food:

Shelf SubType = Alcohol

Density of Alcohol (ρ_{alc}) = 1191.67 kg / m^3

Emissions Factor of Alcohol (EF_{alc}) = 0.489 kg CO_2 / kg

# of Shelf Levels ($\#_L$) = 3

Length of Shelf (L_s) = 2.88 m

Width of Shelf (W_s) = 0.92 m

Height of Shelf (h_s) = 4.31 m

% of Area Used ($\%_A$) = 50%

% of Height Used ($\%_H$) = 50%

Dimensions of Shelf Structure (D_s) = 0.08 m x 0.08m

Usable Shelf Area (A_U) = (L_s - 0.16) * (W_s - 0.16) = 2.0672 m^2

Usable Shelf Volume (V_U) = A_U * (h_s - (0.08 * $\#_L$)) = 8.413504 m^3

Volume of Alcohol (V_{alc}) = $V_U * \%_H * \%_A$ = 2.103376 m^3

Mass of Alcohol (m_{alc}) = $\rho_{alc} * V_{alc}$ = 2506.530078 kg

Emissions of Alcohol (E_{alc}) = $m_{alc} * EF_{alc}$ = 1225.693208 kg CO_2

Shelf Structure:

Shelf Base Type = Refrigerator

Refrigerator Surface Density (SD_{fridge}) = 248.4 kg / m^2

Mass of Fridge (m_{fridge}) = $SD_{fridge} * L_S * W_S$ = 658.16064 kg

Emissions Factor of Fridge (EF_{fridge}) = 0.0117 kg CO_2 / kg

Emissions from Fridge (E_{fridge}) = $EF_{fridge} * m_{fridge}$ = 7.700479 kg CO_2

Total:

Emissions = $E_{fridge} + E_{alc}$ = 1233.393688 kg CO_2

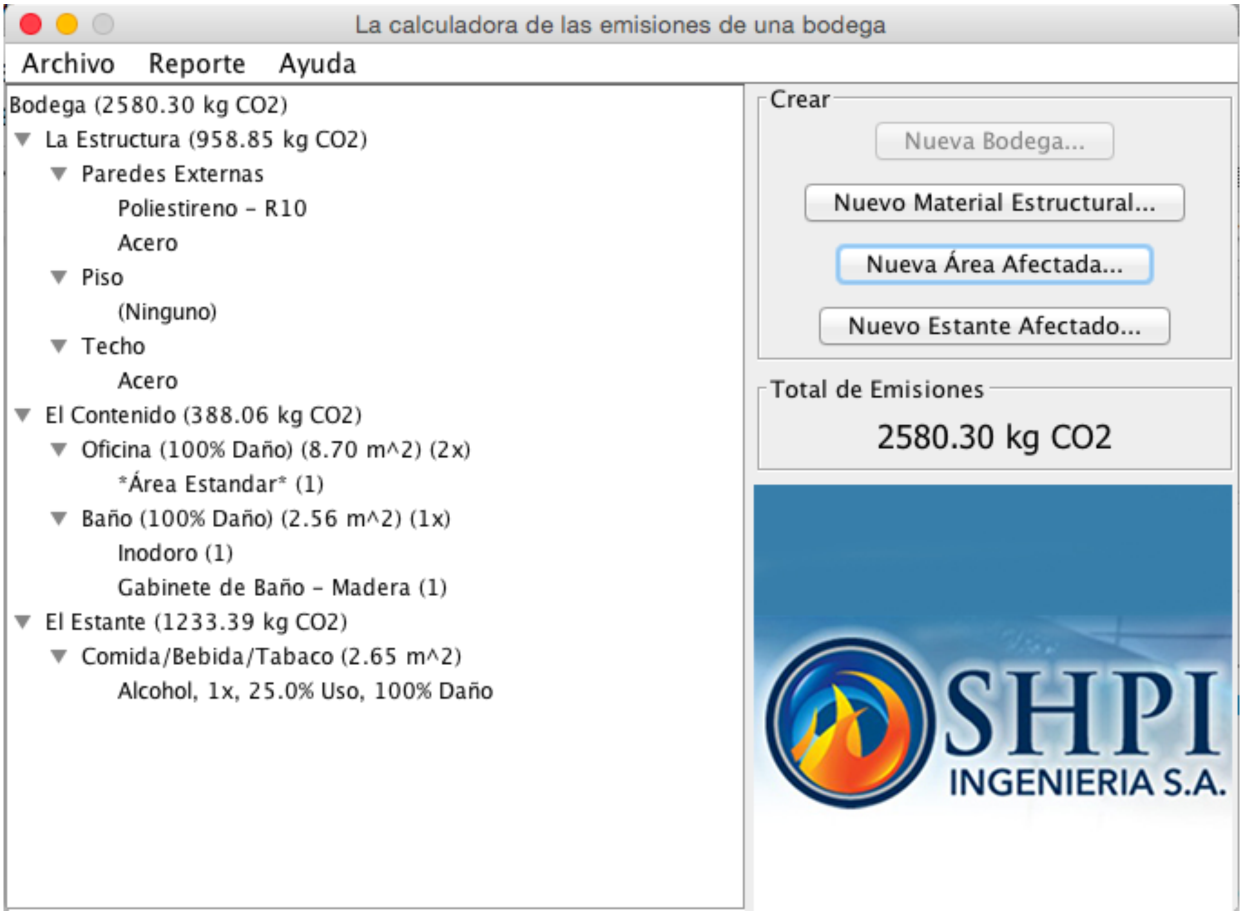
Model Input of Food Shelving

<u>Total:</u>

Total Emissions from Warehouse = Total Emissions from Shelving + Total Emissions from Contents + Total Emissions from Structure = 2580.295872 kg CO_2

Total Emissions from Warehouse (from model) = 2580.30 kg CO_2

% Error in Emissions = | (2580.295872 - 2580.30) / 2580.295872 | = 0.0002% error = 99.9998% accuracy



Overall Model Input