Visualization of Sustainable Construction

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ABSTRACT
The excessive amount of Green House Gas (GHG) emissions in the recent years has caused a major global warming problem. Although historically GHGs have been a natural source of warming in the atmosphere, yet in the past two decade or so, their adversarial effects have been more sensed and reported. Among the sources of these emissions, transportation is responsible for more than 50% of these released emissions. Among all transportation subcategories, construction industry is one of the major producers of these emissions. Despite the main contribution of the construction industry, there has been minimal effort in effective sensing and visualizing of these emissions. Therefore in this paper, we describe a system for simulating and visualizing the GHG emission from construction equipments during the lifetime of an actual construction project. Based on the results of the simulation, the required number of trees to neutralize these emitted GHG is also visualized.

Categories and Subject Descriptors
D.3.3 [**java + vtk**]: *–polymorphism, encapsulation, inheritance, advanced visualization tools.*

General Terms
Design.

Keywords
Sustainability, Construction, Pollutant Emission, Green House Gas, Visualization.

1. INTRODUCTION
Climate change refers to long-term fluctuations in the climate system. Examples of these changes include, but not limited to, changes in temperature, precipitation, and wind. Changes in climate are driven by changes in the amount of present radiation in the earth's atmosphere. The earth's surface absorbs radiation from the sun and this energy is then redistributed by the atmospheric and oceanic circulation and radiated back to space. In general, incoming solar radiation is approximately balanced by the outgoing terrestrial radiation. Some of the gases existing in the earth's atmosphere help the process of keeping the radiation from the sun. These gases are known as Green House Gases (GHGs), since they have such an effect as greenhouses (California Energy Commission, 2002).

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Greenhouse effect keeps the earth warm. Without these effects, the earth's surface would be about 60 degrees Fahrenheit colder than average (the average earth's temperature is about 45ºF). However, the excessive man-made greenhouse gases is altering the process in which naturally occurring greenhouse gasses trap the sun's heat before it can be released back into space. A factor altering the distribution of radiative energy is likely to affect climate (PEW Center on global climate change, 2002).

Although greenhouse effect has been taking place for billions of years, over the last 50 years, excessive greenhouse gas emissions (i.e. human-induced emissions) are believed to be responsible for most of the observed earth's warming known as global warming. The United States produces more than 7 billion metric tons of GHG (CO2 Equivalent) yearly which places this country as one of the most GHG producer of the world right next to China. Among all the greenhouse gases, CO2 accounted for the largest percentage (83%) and thus required prompt action to reduce (California Energy Commission, 2002).

Operation and maintenance of buildings and infrastructures count for more than 39% of the US's greenhouse gas emissions (EIA, 2003). In addition, transportation sector is the largest contributor of GHG emission by a share of 28% which is slightly lower than the highest share of 30% from the industry section (PEW Center on global climate change, 2002). Since construction industry is solely responsible for more than 16% of total transportation and considering the share of buildings operation and maintenance in the total GHG emission, it is easy to see the construction sector has a great potential for controlling and minimizing the amount of GHG emissions (Junnila et al. 2006). Therefore any decision that is taken towards lowering these emissions, can significantly affect the total emission at large.

Among reporting techniques, visualization has proved itself as one of the most effective tools in allowing practitioners to make control decisions and has a great potential in minimizing the time required to describe and explain situations and alternatives in coordination meetings (Golparvar-Fard et al. 2006). Thus, the authors propose visualizing construction GHG emissions in order to provide owners, construction managers as well as other key project stakeholders with visual representation of the amount of GHG that their projects are accountable for. In addition to project participants, there is a consensus among the public especially those living in close proximity of construction sites that construction is one of the most polluting industries and their daily lives are being affected adversely due to these emissions. The proposed visualization system can provide them with realistic representations of the emissions that ultimately lead to a more justified assessment.

Planting trees remains the cheapest and the most effective means of drawing excessive GHG emissions from the atmosphere (Prow 2009). Plants and especially trees absorb GHG from atmosphere during their photosynthesis and release Oxygen as the output. This phenomenon is one of the most natural ways in absorbing GHG from the air and thus can be used by construction project managers as a way to neutralize their produced GHGs. Based on this concept, the implemented system converts the amount of GHG emission and transforms it to the number of trees required to compensate for the loss and creates a metaphor that shows how green the analyzed construction project is.

2. OBJECTIVE

The goal of this research is to develop a visualization system that can effectively demonstrate the share of the construction industry in the overall GHG emissions. In order to equip the reader with real application of the proposed system, the Student Dinning and Residence Hall construction project on the campus of the University of Illinois at Urbana-Champaign is selected as a case study. This case study allows the authors to visualize the share of our campus construction projects to the overall GHG emission. In addition, the system provides users with the number of trees needed to be planted to compensate the loss caused by the generated GHG. Furthermore it allows control decisions to be made easily and quickly, in turn reducing the impact of GHG emissions and to bring awareness to the stakeholders and affected public.

3. RESEARCH BACKGROUND

Recently, there has been a significant growth in efforts towards visualization of GHG emissions. One of the early efforts that were undertaken by the Australian government is in form of a TV commercial and was entitled as Black Balloon Campaign. In the produced commercial advertisement, CO_2 emissions are represented with black balloons. In this work a video visualization was used to inform viewer about the fact that annually every Victorian household produces and emits over 12 tones (240,000 balloons) of GHGs. The results of this visualization were significant especially in bringing public's attention towards to the importance of proper controls on the operation of the household apparatuses. However the result was mainly in the form of storytelling and did not focus much on reduction solutions. Figure 1 demonstrates a screen shot of this visualization (http://www.awidernet.com/2008/05/28/visualizing-co2-emissions/ , 2009).

Figure 1- Black Balloon Visualization of CO2 emissions

NASA (2009) funded a research project called "carbon dioxide map of U.S." which was further released as an extension to the Google Earth. It provides detailed carbon dioxide emissions from fossil fuels combustion and displays fossil fuel emissions by the hour, geographic region, and fuel type.

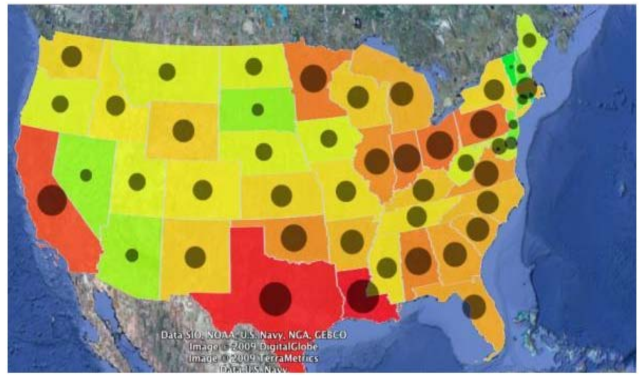

Figure 2- NASA-funded Google Earth CO2 emissions map

Ceip (2009) prepared a visualization of GHG emission for each region over the world. Their effort visualizes gridded data in Google Maps/Earth based on each country and selected specific gas on top of the current existing geographical maps. As shown in figure 3 and 4, the grid sizes were relatively large and were only able to cover large areas such as cities.

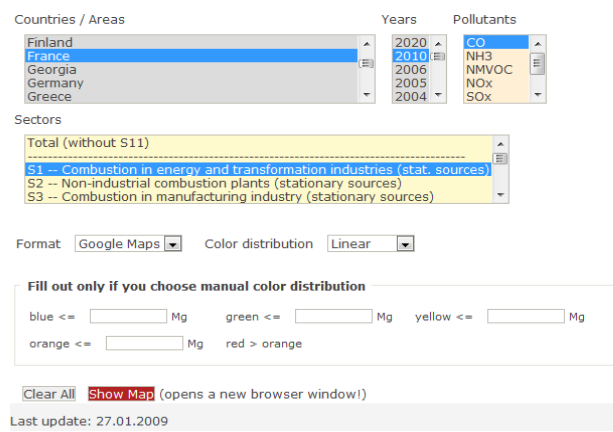

Figure 3- Input screen of the GHG visualization system

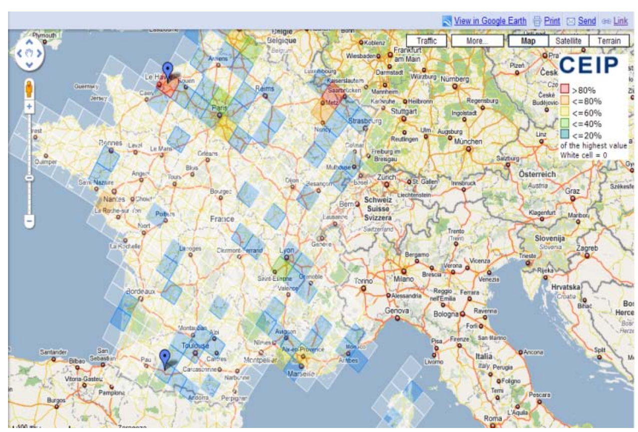

Figure 4- Grid-based GHG emission data in Google map

Finally, White and Feiner (2009) proposed a visualization technique for urban site visits and the generated CO. Their efforts lead to a novel visualization of sensor-based CO data in an Augmented Reality (AR) environment. However, their main focus of this system was on publicizing the application of their visualization toolkit rather than focusing on CO gas emission data. Figure 5 shows screen shots of their visualization as well as the AR technique implemented to visualize the sensed CO emissions.

Figure 5- Photo of the CO emission visualization in the area

Among majority of the research efforts conducted on visualization of GHG emissions, the main focus has mostly been on GHG emissions sourced either by fossil fuels or operation and maintains life cycle of building and infrastructures. Since the construction of these building and infrastructures significantly accounts towards the overall GHG emissions, therefore the emphasis of this research has been placed on visualization of these emissions during the construction phase of any building or infrastructure project. In this paper, we have looked into simulation of carbon dioxide emissions during construction of the Student Dining and Residence Hall project on the campus of University of Illinois, Urbana-Champaign. Based on simulation of these emissions over the first year of its construction, the carbon dioxide generated and expected is visualized. In the meantime, a metaphoric representation of the number of trees required to compensate the loss due to carbon dioxide emissions is also visualized.

In the following sections, we look into the engineering of the proposed system. First we look into the specific goals of our project, its potential users, how the system could be used. Then we look into how the inputs and outputs of the system as well as how emissions are simulated and visualized. Finally the results of the system are presented and usability, efficiency as well as the innovative components of our system and discovered patterns among the visualized data are discussed.

4. ENGINEERING OF THE SYSTEM

In order to visualize GHG emissions during the construction phase of a project, we have looked into a-similar-to Geographical Information System (GIS) representation of the site. Not only a map representation has the ability of visualizing construction site level activities, but also allows the transportations that lead to the construction site to be visualized. Furthermore, through the means of visualization of wind flows, it allows the concentration and sequestration of carbon dioxide emissions to be visualized. In the following sections, specific goals, potential applications, usability of the system as well as the inputs and outputs are thoroughly discussed. Finally the efficiencies and the innovative aspects of the system are presented.

4.1 Goals

The following outlines the specific goals of design and implementation of our visualization system for representation of sustainable construction operations:

1. Bring awareness to owners, construction management companies as well as contractors and other project stakeholders on the importance of controlling excessive emissions;
2. Visualize construction activities that generate Green House Gas emission sand bring focus and awareness to those activities that have high rate of emission generating;
3. Visualize equivalent number of trees required to compensate the loss due to the GHG emissions;
4. Bring awareness to different project Stakeholders as well as the public interested in the neighborhood construction projects;
5. Provide construction contractors with an effective tool to present its effort in reducing GHG emission which indeed could be used as a metric of how green the contractor is.

4.2 Potential Users

There are three main potential user groups for this visualization system. One potential group of users of this system is the project stakeholders' group, i.e., owners, client representatives and facility managers. The second user group of this system consists of construction management companies as well as contractors and subcontractors. Finally the last group among the user group is the public user's group who are interested in tracking status of the construction projects especially those happening in their neighborhood.

4.3 Inputs

In order to study the realistic nature of our case study's GHG emissions, we have looked into the existing construction plans. These plans incorporate construction project schedules. These schedules clearly outline construction activities, type and number of equipments and machinery required for each activity as well as the emissions estimated based on initial equipment manufacturer's information. Given this set of information, a two dimensional Gaussian distribution for the emission of each machine is simulated. For each construction activity outlined in the construction plan, first all the machineries used are listed. For each of these equipments within the construction activity, a 2-dimensional discrete Gaussian distribution is estimated based on the following formulation:

$$f(x,y) = Ae^{-\left(\frac{(x-x_0)^2}{2\sigma_x^2}+\frac{(y-y_0)^2}{2\sigma_y^2}\right)} \qquad (1)$$

Where x and y represent local proximity to the center of the pollution. This formulation for GHG emissions is calibrated based on equipment manufacturer's information. Once this distribution is known, GHG emissions are simulated based on the construction operational path. Figure 6 further demonstrates the discrete distribution function of these GHG emissions.

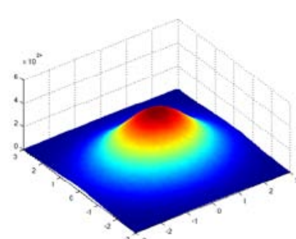

Figure 6- Two dimensional Gaussian distribution

In addition to these sets of information, the meteorological distribution of wind is collected over the construction site. This information allows the concentration as well as sequestration of carbon dioxide emissions to be further studied.

4.4 Outputs

The main outputs of this system are categorized as follow:

1. Visualization of GHG especially CO2 emissions over the geo-spatial configuration of the construction site as well as its close proximity; this component of the system is further categorized into these subcategories:
    a. Visualization of daily CO2 emissions;
    b. Visualization of the summation of carbon dioxide emitted prior to the day under study;
    c. The expected emissions due to the project in the remainder period of construction;
    d. Representation of wind flow and its potential effect on concentration and sequestration of carbon dioxide emissions.
2. Visualization of trees required to be planted to compensate these emissions. Prow (2009) reports that a single mature tree can absorb carbon dioxide at a rate of 48 lbs/year and release enough oxygen back into the atmosphere to support 2 human beings. Based on this ratio and the results of the conducted simulations, two tree representations were generated:
    a. The numbers of trees required to compensate the carbon dioxide generated from the start of the project until today;
    b. The estimated number of trees required to be further planted to neutralize the adversarial effects of carbon dioxide emissions.

In the following section, the concepts of usability, understandability, efficiency as well as the innovative components of the system are further discussed in details:

4.5 System Usability

The visualization system was designed to have three major components:

Visualization of the emissions over a map representation of the construction site and its close neighborhood: In order to make sure the system would be effectively used by the target user groups, the authors decided to further augment the visualization system with a representation of its data value. For example in order to visualize the CO2 emissions, a grid structure was generated and over each node, a bar representation of the emissions generated from the beginning of the project was utilized. Consequently another bar representation was utilized to further visualize the estimated remainder of the CO2 emissions. The height of these bars was proportionally distributed between the aforementioned emissions. In addition, the discrete Gaussian distribution of the emissions was visualized using a color spectrum. Color spectrum allows different values of the emissions to be visualized simultaneously. Finally the wind visualization was represented using streamlines in addition to arrow heads. The stream lines are effective visualizations that are used by engineers and therefore have a high rank in terms of their usability.

Visualization of trees: As mentioned in the outputs of the systems, two categories for visualization of trees were designed:

1. Designing visualization for the numbers of trees required to compensate the carbon dioxide generated from the start of the project until today. These trees are visualized using a red color.

2. Designing visualization for the number of trees estimated to be required for compensating the carbon dioxide emissions. The authors made this representation based on a single concept that tree visualization can bring a large attention towards the actual or potential damage caused by these excessive carbon dioxide emissions as well as the important of control decisions to be made quickly to compensate these emissions.

The User Interface: The user interface was designed to allow different alternatives to be switch on and off and allow user groups to study different configurations over both the map as well as its metaphoric tree representation. Meanwhile the map interface to be designed in a fashion allowing users to use projective transformations on the visual representation and modify the vantage point to find the most effective perspective.

4.6 Innovation of the system

The presented system marks the first visualization system for representation of CO2 emissions generated during construction phase of building or infrastructures' projects. The authors think the tree visualization certainly brings attention to the adversarial effects of these excessive carbon dioxide emissions. These components are further discussed later in the paper. The user interface is designed as simple as possible in order to let different types of users with different levels of computer skills to quickly use the system. It is expected that the user interface can almost instantly be used without any need of effort from the users to learn the environment.

5. IMPLEMENTATION OF THE SYSTEM

The proposed system is implemented using Java and vtk visualization library. Each of the following sections further elaborates on the implementation of each component of the system:

5.1 User Interface

Figure 6 shows a snapshot of the implemented user interface. As observed, the user has the capability of studying different information independently or in an integrated fashion.

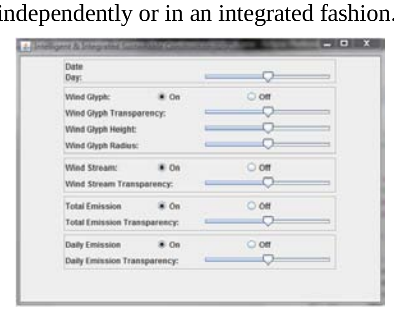

Figure 6- The layout of the user interface

5.2 Tree Visualization

Figure 7 illustrates the symbolic representation of trees. In this case 3 trees (color coded in red) need to be planted to compensate for the carbon dioxide emissions until the run date of the system while it is estimated that there will be 5 other trees that are needed to be planted to compensate the remainder of emissions. Any decision that is made to reduce the emissions can minimize the need for further planting of trees.

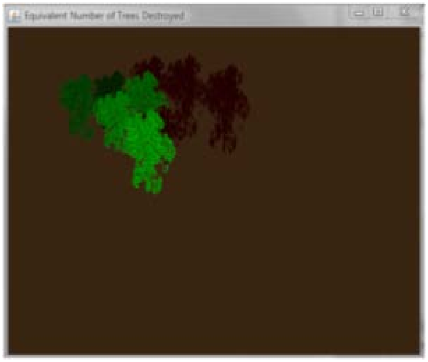

Figure 7- The symbolic tree visualization

5.3 The focal visualization

The main visualization component of the system represents the geo-spatial configuration of the site at a particular time. In this case, the emissions generated from the operation of the machinery are visualized using color coded Gaussian distributions. Figure 8 further illustrates the emissions by representing two key areas where construction operations have been conducted over a working day. In this case, 5 construction machines more or less with the same potential for emissions have been used. As observed, the Gaussian distribution shown on the upper right corner of this figure represents a more concentrated distribution of carbon dioxide and this is due to the fact that two machines in close proximity of each other were operating. As further observed, the three upper distributions show that construction operations have been generating emissions in close proximity of two of the student residence hall facilities.

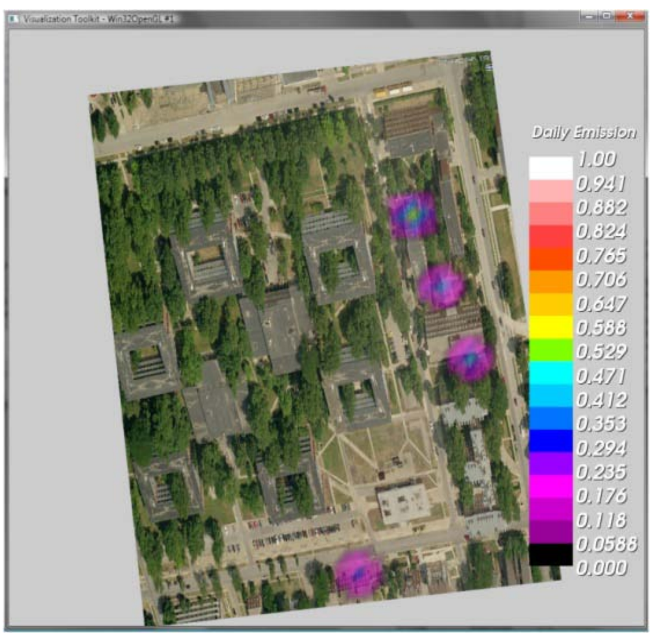

Figure 8- The visualization of daily carbon dioxide emissions concentrated over machinery locations.

The overall estimated emissions is also visualized using the bar presentation. Figure 9 further illustrates such configuration. This type of representation allows the project stakeholders to study their operational paths and come up with alternatives that potentially have the least destruction to the neighborhood which in this case is the student residence and dormitory area.

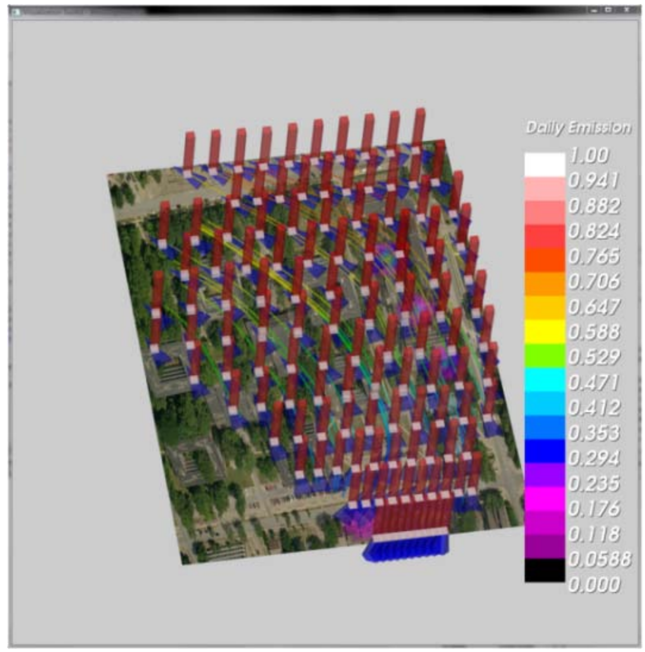

Figure 9- The GIS visualization of carbon dioxide emissions as well as wind streamlines.

One of the main points of interest in implementation of this system was to provide users with the ability of studying concentration of carbon dioxide emissions. Therefore wind streams and wind glyphs have been represented on a daily basis to provide the opportunity of having such information be studied either independently or in junction with the emissions generated and consequently different construction operation alternatives to be studied and emissions to be estimated. Figures 10 and 11 further visualize such representations. As observed, the wind has been visualized using streamlines where different colors are showing different wind velocities. Furthermore the 3D bar representation visualized the amount of emissions estimated to be generated throughout the remainder of construction operations.

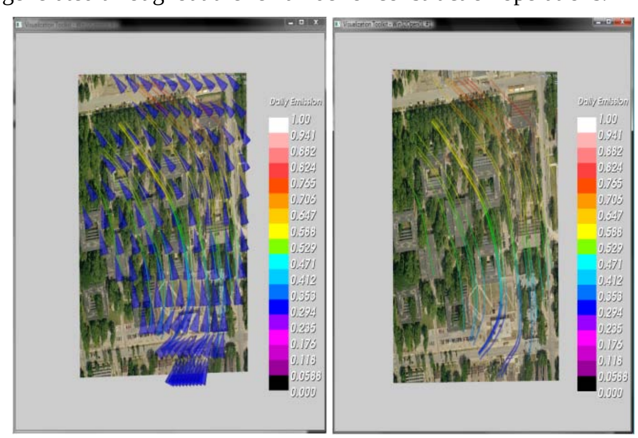

Figure 10- The visualization of wind streams and wind glyphs averaged over the period of a working day.

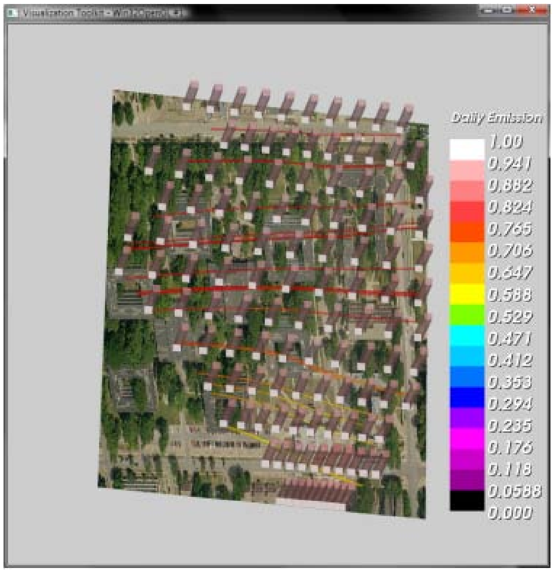

Figure 11- The visualization of the wind streamlines with its potential effect on carbon dioxide concentration.

6. DISCUSSIONS

We have conducted a case study using the presented visualization system over the first time-span of Student Dining and Residence Hall construction project. The data used to represent the emissions and the meteorological changes are all real world data which allows us to further discuss the observations and draw conclusions based upon those. One of the main important patterns that are observed in this visualization is the distribution of concentrations of carbon dioxide emissions. The resulted visualization showed some interesting trends among data which were hidden from users prior to the visualization. The visualization results showed that for the case study project, the first quarter of project lifespan produces the least GHG emission. One of the possible reasons could be the fact that during this phase minimum number of equipments is involved on the construction site. In addition, the second quarter of project lifespan generates the highest amount of GHG which is mostly the time that due to excavation lots of trucks and excavation equipments were present at site. It is only during the third quarter that GHG emission is lowered. One possible reason could be the fact that at these stages construction managers usually have to make decisions on how to improve the performance of the equipments and thus the emission is reduced. Finally, the fourth quarter has lower GHG emission than all the others but slightly more than first. The reason could be the fact that at the end of the project most of the remaining activities are labor intensive rather than equipment intensive and thus many of the equipments are moved away from the site.

The proposed visualization system allows simulating the emissions of a specific construction schedule and visualizing the emissions. This in turn allows project stakeholders to study different construction operation alternatives to minimize the impact of these emissions, visualize and understand how potential carbon dioxide can be sequestrated in the close proximity of emission sources. In the meantime, the tree visualization allows key decision makers of a project including the owners to be aware of the adversarial effects of their projects and try to come up with better and more sustainable construction practices to minimize their impacts. This ultimately can lead to formation of legislative guidelines specifically targeted to the operational stages of a construction. Currently with the increasing support and funding for sustainable infrastructures, construction companies are required to follow LEED guidelines (US Green Building Council, 2009). Although one of the targeted measurements in LEED certification is to reduce carbon dioxide emissions, less attention has been placed towards the construction phase itself. Our observations show that a proper and informative visualization of sustainable construction practices can ultimately lead to a better awareness of all project stakeholders and when implemented as guidelines and requirement, can impact the minimization of GHG emissions at large. This research experiment raises further questions: How the emissions generated from construction operations can be less adversarial? Is there a need to change construction machinery or are there ways for which we can modify our existing plans and strategies for performing a construction practice without affecting the work productivity? Are there ways for which we can require contractors to plant equivalent trees to compensate the damage they cause to atmosphere by the GHG emissions from the equipments they used in their activities?

In order to be able to properly answer these questions, our presented system needs to be further equipped with tools that will allow emissions to be monitored and compared to the simulated values to further study and analyze if any change in construction practice or machinery can ultimately result in lower emissions. As a short term solutions, probably planting trees to compensate the loss due to the emission will be the most reasonable solution, however in long term further studies are needed to be conducted to see how operations could be optimized. The authors also believe that further case studies are required to properly appreciate the benefits of implementing such visualization systems for sustainable construction practices.

The bottleneck associated with the implementation of such visualization is the lack of available guidelines. Currently LEED, the most dominant guideline in the United Stated, does not have specific procedures for contractors to track their carbon dioxide emissions and ultimately reduce their impacts. Besides contractors are historically not much in favor of these changes, since there is a perception that these guidelines may impact the productivity of their workforce and ultimately reduce their profit margins. If these visualization systems are further prototyped and implemented it can bring awareness on these emissions and allow contractors to come up with innovative solutions for changing their work plans without affecting the productivity of their workforce or machinery.

7. CONCLUSIONS

The excessive amount of Green House Gas (GHG) emissions in the last decade or so has caused a major global warming problem. Although historically GHGs have been a natural source of warming in the atmosphere, yet in the past two decade or so, their adversarial effects have been more sensed and reported. Clearly construction industry is one of the major producers of these emissions. Despite the main contribution of the construction industry, there has been minimal effort in effective sensing, analyzing and visualizing these emissions. Therefore in this paper, we describe a system for simulating and visualizing the GHG emission from construction equipments during the lifetime of an actual construction project. Based on the results of the simulation, the required numbers of trees to neutralize these emitted GHGs are also visualized. The preliminary results of implementing this system for the Student Dining and Residence Hall construction project shows that a proper visualization allows project stakeholders to study different construction operation alternatives and see how they can modify/revise their work plans that ultimately has less adversarial effect on the overall GHG emissions.

Further research needs to be conducted with more case studies on how such visualization system could effectively be implemented. Also further studies are required to see if these simulations, sensing and visualizations can form guidelines and protocols and ultimately become a part of the existing procedures such as LEED.

8. ACKNOWLEDGMENTS

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