Global Reduction of Excess CO_2 Emissions in Construction

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Prepared for **The Office of the Mayor**
of **Ruston, Louisiana**
by **Daniel Campbell**
in fullfillment to **The Sustainability Consortium**
at **Louisiana Tech University**
on **10 February 2017**

Abstract

In recent decades, CO_2 emissions reduction has grown to become one of the greatest global challenges of our time. The biggest contributor to global CO_2 emissions is the construction and operation of buildings. Adjustments to material production or alternative material use will reduce global CO_2 emissions. Three solutions for global excess CO_2 emissions reduction are use of photovoltaic (PV, or solar) electricity in steel production, production of GeoPolymer concrete, and use of Cross-Laminated Timber (CLT) in construction. To determine the best strategy, three criteria were used to judge the three solutions: global reduction of CO_2 emissions, cost to the end user, and likelihood of adoption. After measuring all three solutions against the criteria, it was determined that Cross-Laminated Timber is the best strategy for reduction of global excess CO_2 emissions. CLT is the best strategy because, if used in less than 1% of future buildings, it will sequester, or absorb, more CO_2 than humanity currently emits into the earth's atmosphere.

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Executive Summary

In recent decades, CO_2 emissions reduction has grown to become one of the greatest global challenges of our time. The biggest contributor to global CO_2 emissions is the construction and operation of buildings. Taking steps toward reducing the CO_2 emissions released into the atmosphere by buildings can have a measureable impact on the state of the atmosphere. Several strategies can be used to reduce the lifetime CO_2 footprint of construction. While programs such as Leadership in Energy & Environmental Design (LEED) are pressing architects and engineers to intelligently design buildings with available building materials, an excellent way to reduce overall CO_2 emissions is to reduce the footprint construction materials have on the environment.

Three changes to construction materials that could help to reduce global CO_2 emissions are use of photovoltaic (PV, or solar) electricity in steel production, production of GeoPolymer concrete as a replacement for Portland cement, and the use of alternative building materials such as Cross-Laminated Timber (CLT). To determine which change is best, three criteria are used to compare the solutions. The three criteria are the global reduction of CO_2 emissions, cost to the end user, and likelihood of adoption.

Reducing steel production's 5% of yearly global CO_2 emissions will require replacing typical CO_2 emitting electricity sources with PV electricity. A transition to PV electricity in steel production also allows for growth in molten oxide electrolysis steel processing, which uses iron or iron oxide to produce steel and oxygen and emits zero CO_2. This strategy allows for a significant reduction of global CO_2 emissions, has the potential to reduce electricity costs during production by up to 30%, has the likelihood of creating an interplanetary steel market, and is highly likely to be adopted by the global steel industry.

Cement, which accounts for 5% of total yearly global CO_2 emissions, has the potential to be replaced by GeoPolymer concrete. Using slag–a by-product of steel production–researchers have produced a substitute for Portland cement that is 60% stronger than standard concrete. GeoPolymer concrete promises reduction of global CO_2 emissions by 6% and the addition of revenue to the steel industry, but the technology is still in the research and development phase and is not likely to be adopted by industry professionals in the near future.

Cross-Laminated Timber, or CLT, is an alternative building material that processes standard dimensional lumber into massive timber construction components. CLT is more durable than standard wood framing methods, more resistant to fire, and more resilient to natural disasters. Additionally, it sequesters, or absorbs, CO_2 from the surrounding atmosphere. If only 1% of the 4.8T square feet of buildings expected to be built globally in the next year are constructed using CLT, those buildings would sequester 150% of the current global CO_2 emissions. Cross-Laminated Timber is positive in every measurable category and is highly likely to be adopted and implemented in the near future.

My recommendation for global CO_2 emission reduction is Cross-Laminated Timber. Although transitioning to PV electricity sources in steel production has a number of positive consequences and the added appeal of the first interplanetary industry, CLT is produced with trusted building materials, has the potential to reverse global excess CO_2 emissions. CLT is also likely to be an economic success and likely to be adopted by the construction industry. The second best strategy is the use of PV electricity in steel production. It has the potential for a significant CO_2 emissions reduction and exciting prospective economic growth, but lacks the overall impact that CLT does. I would not recommend GeoPolymer concrete as a viable option while it is still in the research and development phase. Despite all that it promises, there are still too many variables. The solution for excess global CO_2 emissions reduction is Cross-Laminated Timber.

Introduction

Purpose

The purpose of this technical report is to review the issue of global excess CO_2 emissions and how to solve the problem by making adjustments to the materials used in construction. I will begin by introducing the problem of global excess CO_2 emissions, and will propose three potential solutions and three criteria to judge the solutions. I will conclude by recommending the best solution for reduction of global excess CO_2 emissions.

History of the Problem

According to *CO² Earth*, a citizen led, independent initiative, yearly global CO_2 emissions are nearing ten gigatons (10B tons) while earth can only naturally absorb approximately four gigatons per year ("Global Carbon Emissions" par. 8). Buildings alone account for 39% of CO_2 emissions in the United States, and nearly half of those emissions are a result of producing the materials we build with (*Buildings and Climate Change* 1). In order to reduce or reverse the accumulation of excess CO_2 in our atmosphere, we must begin at the source of the problem and adjust the materials we use for construction.

If the construction industry and other liable industries take steps to reduce or remove their carbon emissions from the global total, we can help Earth repair its atmosphere and return the planet to a healthy state.

Recent Studies

Terms like *global warming* and *climate change* are globally recognizable, and most of the world's population is aware that "87 percent of all human-produced carbon dioxide emissions come from the burning of fossil fuels like coal, natural gas and oil" ("Carbon Emissions" par. 5). The awareness of CO_2 emissions comes from decades of research in a variety of fields that all concluded unanimously that there is too much carbon in the atmosphere. The acceptance of the theories of excess CO_2 emissions has led to a human-scale focus on sustainability, economics, and harmony with nature. Buildings account for a significant portion of global emissions, resulting in the formation of entities such as the U.S. Green Building Counsel (USGBC) and Leadership in Energy & Environmental Design (LEED) to minimize the impact of architecture on Earth.

Research Procedures

To determine which solution for the reduction of global excess CO_2 emissions is the best option, I have conducted extensive research on several potential solutions. To gather a variety of reliable information, I have reviewed dozens of reports from the U.S. Geological Survey, books specific to the solutions, and various academic journals. I have also compiled data from a variety of sources, and interviewed an experienced industry professional and a notable architectural historian. Using these resources, I was able to compile this report to outline the best solution for the reduction of global excess CO_2 emissions.

Global Reduction of Excess CO_2 Emissions in Construction

The Problem

Carbon emissions, such as CO_2, are a fast-growing threat to humankind; we are producing approximately 10 gigatons (10 billion tons) of CO_2 per year, while our planet can only naturally absorb around 4 gigatons. If our air is to remain breathable, every CO_2 producing industry must make efforts to reduce or reverse the production of CO_2 emissions. Cement production accounts for 1.35 billion tons of global CO_2 emissions annually, so if there is a way to reduce emissions, the global impact would be significant (Omar et al. 1443-1451).

Construction materials are the largest contributor to the approximately 39% of global carbon emissions produced by our buildings. The challenge with building materials is the balance between zero environmental impact and price to the end user.

Making changes to existing materials or adopting new ones are measurable ways of reducing global excess CO_2 emissions. Three potential changes that could help are using photovoltaic electricity in steel production, production of GeoPolymer concrete as a replacement to Portland cement, and the use of alternative building materials, such as Cross-Laminated Timber (CLT). Each change will be judged based on the criteria of the global reduction of CO_2 emissions, cost to the end user, and likelihood of adoption.

The Solutions

Many changes to construction materials have the potential for measurable global CO_2 emissions reduction. The first solution is the use of photovoltaic electricity in steel production. The second change is the production of GeoPolymer concrete as a replacement to Portland cement, and the third is use of alternative building materials, such as Cross-Laminated Timber (CLT). Each of these changes has the potential to reduce CO_2 emissions.

Solution 1

Photovoltaic Electricity in Steel Production

The first change to construction materials that has the potential to lower CO_2 emissions is using photovoltaic electricity in steel production. According to the World Steel Organization, approximately 35% of the energy used in steel production comes from electricity (*Energy Use* 1). Currently, the majority of the electricity used during steel production comes from sources that produce CO_2 emissions, such as coal, natural gas, and nuclear power sources. Photovoltaic electricity, although expensive to install, is a zero emissions alternative to carbon-based electricity sources. A global transition to photovoltaic energy production is already under way in other sectors of industry, including construction.

Solution 2

GeoPolymer Concrete

The second change to construction materials that has the potential to lower CO_2 emissions is the production of GeoPolymer concrete. Geopolymer concrete is a mix of concrete that uses slag – a by-product of steel production – as cement. During steel production, "slag remaining after [steel production] is usually equivalent to about 10% to 15% of the crude steel output" (Van Oss 70.2). Portland cement, the most commonly used binder in concrete, is accountable for more than 5% of global CO_2 emissions (Rubenstein par. 1). If all of the slag were used to create GeoPolymer concrete, it would reduce Portland cement emissions by 15%, or nearly 1% globally.

Solution 3

Cross-Laminated Timber

The third change to construction materials that has the potential to lower CO_2 emissions is using alternative building materials. Cross-Laminated Timber, already popular in Europe and Canada, is defined as "a massive plywood panel replacing thin layers of veneers, typical in plywood, with dimensional finger-jointed lumber" (Mayo 17). The massive timber components pictured in **Figure 1** emit zero carbon emissions and may reverse the excess emissions entirely. If even a minute portion of the global building stock were built from CLT, those buildings could potentially sequester, or absorb, all of the excess CO_2 emissions that are created worldwide.

▲ **Figure 1** *Building Thistleton Waugh CLT Tower in London* (Slotover-Smutny)

The Criteria

To determine which change to construction materials is best suited to lower global CO_2 emissions, I will use three criteria to judge the three solutions. The first criterion is the total global reduction of CO_2 emissions. The second criterion is the total cost change to the end user. The third criterion is the likelihood of adoption. A comparison of each solution using these criteria will present a clear strategy for global CO_2 emissions reduction.

Criterion 1

Global Reduction of CO_2 Emissions

The first criterion is the total global reduction of CO_2 emissions. I will take each construction material change and determine how it will affect the total CO_2 emitted into the atmosphere per year. The total CO_2 emissions for each material is the most important factor. Therefore, whichever solution provides the largest reduction in CO_2 emissions will likely be the best solution.

Criterion 2

Total Cost to the End User

The second criterion is determining the total cost effectiveness to the end user. No matter how beneficial something might be to the environment, if it is not fiscally viable, it will not become an industry standard. Lifetime cost is the primary concern of the cities, investors, construction professionals, and architects who make decisions about our built environment.

Criterion 3

Likelihood of Adoption

The third criterion is likelihood of adoption. Determining which solution will be quickly embraced by the industries will help when choosing the best overall solution. A solution that is likely to be easily implemented or accepted by popular opinion may be the material change solution that can reduce global CO_2 emissions most quickly.

Criterion 1

Total Global Reduction of CO_2 Emissions

Using the first criterion, total global reduction of CO2 emissions, I will compare the proposed solutions to determine which material change is the best for this criterion. The material change that results in the largest reduction in CO2 emissions will likely be the best overall option.

Solution 1

Photovoltaic Electricity in Steel Production

Steel is the second most widely used material in construction, and incidentally, the second largest CO^2 emitting material in the industry. As steel production emits 5% of the total global CO^2 emissions each year, there is a lot of room for a reduction (Chandler par. 4). Many gasses are responsible for the majority of the CO^2 emitted by steel production that do not have viable replacements. However, 35% of CO2 emissions are produced fuel for electrical needs. The Massachusetts Institute of Technology reports a partnership with NASA to perfect molten oxide electrolysis, whereby the production of steel can be fueled completely by electricity, produce oxygen as a byproduct, reduce CO_2 emissions to nearly zero, and can even be moved off world – to Mars (Chandler par. 5). Clean production of steel using electicity has the potential to reduce global CO_2 emissions by 5%, as well as produce oxygen as a by-product.

Solution 2

GeoPolymer Concrete

Concrete is the most widely used material in construction. Portland cement, the most common type of cement in concrete, produces 5% of global CO_2 emissions. Recent studies have found that using slag – a by-product of steel production – as a substitute for Portland cement in concrete. In studies published in the *International Journal of Sustainable Built Environment*, GeoPolymer concrete using slag as a replacment for Portland cement is similiar in strength characteristics, as seen in **Figure 2**. During global steel production, up to 15% of raw material input is left over as 17 trillion tons of slag (Mineral 82). If all of the slag worldwide were processed into cement for GeoPolymer concrete, CO_2 emissions from concrete could be reduced by as much as 25%, or 1.25% of the global total.

▶ **Figure 2** Compressive Strength Results of Various Concrete Mixes at Different Ages. Adapted from original document for graphic consistency. (Palankar, Shankar, and Mithun 378-390)

Mix ID	3 Days	7 Days	28 Days	90 Days
Portland Cement	23.1	40.4	55.9	62.8
GeoPolymer	26.3	34.5	49.6	55.7

Solution 3

Cross-Laminated Timber

A recent advancement in the lumber industry called Cross-Laminated Timber, or CLT, presents another potential solution for the global CO_2 emissions problem. CLT is comprised of three to seven layers of dimensional lumber (commonly known as a 2x4, etc.) oriented at right angles to each other and glued. Timber, such as CLT, can sequester, or absorb, CO_2 out of the atmosphere. For example, the average square foot of floor space in a CLT building is equivalent to 1.1 cubic feet of CLT, which can sequester up to 0.313 cubic feet of CO_2 out of the surrounding atmosphere. Navigant Research, the industry leader in global building stock studies, suggests that 4.8 trillion square feet of buildings are expected to be built globally in the next year (Newswire par. 1). Assuming only 1% of the yearly global building stock were constructed of CLT, 15 billion tons of carbon would be sequestered from the atmosphere, which is 150% of yearly global CO_2 emissions.

Conclusion

Cross-Laminated Timber

The solution that best fits criterion one is solution three, the use of Cross-Laminated Timber. CLT is the best strategy for reducing global CO_2 emissions because it has the potential to absorb more CO_2 than all yearly global emissions, reversing the effects on our breathable air. Changes to steel and cement industries have the potential to reduce CO_2 emissions but not by a comparable factor. Overall, the introduction of CLT as an alternate building material is clearly the best solution.

Criterion 2

Cost to the End User

Using the second criterion, total cost to the end-user, I will compare the proposed solutions to conclude which material change is the best for this criterion. The primary concerns of those who build are cost of construction and lifetime cost of use. Therefore, cost to the end-user will weigh heavily when deciding the best overall solution.

Solution 1

Photovoltaic Electricity in Steel Production

Due to consistent demand, the steel industry is very stable and can take the risk of making the sizeable investment into PV based electricity. The global adoption of photovoltaic (PV, or solar) panel based electricity in steel production has the potential to reduce energy prices in steel production by 28% or more over a 25-year period, as seen in **Figure 3**. Additionally, partnership with entities such as NASA presents opportunities for the steel industry to considerably increase supply. A price reduction of steel will affect every industry that processes steel into other products, and will lower the cost of steel to the end-user.

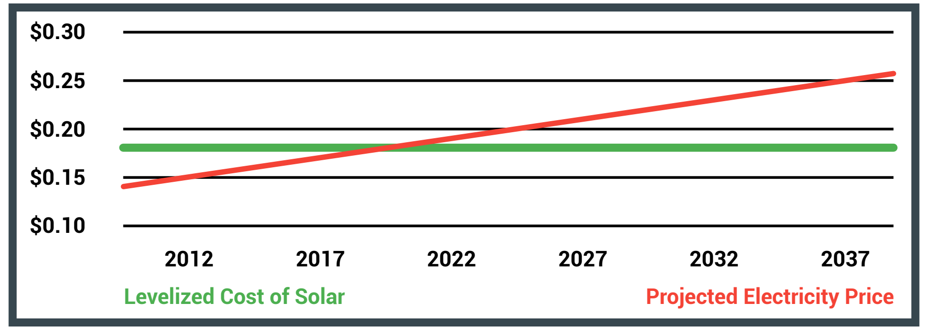

Figure 3 Lifetime Savings from Solar Power
Adapted from original image for graphic consistency (*Lifetime*)

Solution 2

GeoPolymer Concrete

The potential for a material like GeoPolymer concrete to enter the market denotes an advancement in concrete technology and an opportunity for construction professionals to experiment with economical ways of using the new material. Since 15% of concrete is cement, the concrete industry would eventually purchase slag for cement in large quantities from steel manufacturers, which would effectively lower the price of steel. GeoPolymer concrete is of similar strength as concrete that uses Portland cement, but will most likely cost more because of the "high cost for the alkaline solution" needed to bind the slag and aggregate materials (Abdul Aleem and Arumairaj 118-122). Although technologies typically become less expensive as processes are standardized, the implementation of GeoPolymer concrete in construction would increase the overall cost of construction to the end-user.

Solution 3

Cross-Laminated Timber

As modularization, 3D printing, and robotics in Architecture create new industries in construction, a product like Cross-Laminated Timber (CLT) presents economic opportunity in multiple ways. As a production method, CLT is mainly computerized and robotically fabricated, and is therefore highly efficient. CLT also reduces the size of construction teams and overall construction duration as compared to standard construction methods (Mayo 52-56). Finally, massive timber construction is more durable over time than stick-on-stick wood framing methods, more resistant to fire, and more resilient to natural disasters. Cross-Laminated Timber is more economical, therefore more profitable, in every measurable category than standard wood framing, allowing end-users to build inexpensively up front and over time.

Conclusion

Photovoltaic Electricity in Steel Production

The solution that best fits criterion two is solution one, the use of photovoltaic (PV, or solar) electricity in steel production. GeoPolymer concrete is a poor solution because it results in increased cost to the end user. Although CLT marks increased efficiency in all categories, PV electricity use in steel production represents a dramatic change in the entirety of the second most commonly used construction material on the planet. Since steel is used in so many industries, any reduction in steel price will result in a global reduction of the cost of goods and is clearly the best solution for the end user.

Criterion 3

Likelihood of Adoption

Using the third criterion, likelihood of adoption, I will compare the proposed solutions to conclude which material change is the best for this criterion. Likelihood of adoption is an important factor because if a solution is too difficult to change or adopt, the average builder or user is not likely to accept the change.

Solution 1

Photovoltaic Electricity in Steel Production

The use of photovoltaic (PV, or solar) electricity in steel production is a logical step forward in a rapidly advancing industry. Steel production is in a constant state of change as steel manufacturers compete to yield products at the lowest possible cost to their consumers. Dr. Pasquale DePoala, an architecture historian, suspects that any innovation in steel production will attract designers and engineers to manipulate and modify steel to optimize form as it always has. A noteworthy drawback, however, is the probable need for international legislation required to enforce the standard use of technologies in such a large industry. Finally, as the cost of PV technology decreases and/or produces electricity more efficiently, the benefits to the steel industry increase. Therefore, it is likely that global steel industry will adopt PV electricity in steel production.

Solution 2

GeoPolymer Concrete

While GeoPolymer concrete is a noteworthy advancement in concrete technology, it is a concept that is still in the research and development phase. GeoPolymer concrete promises environmental and economic benefits in the future but requires significant investment to realistically develop the technology and production processes. Mostly, the product has not been available long enough to earn the trust of construction professionals, so investment in the technology will be difficult to secure. GeoPolymer concrete will most likely not be adopted by construction industry professionals in the near future.

Solution 3

Cross-Laminated Timber

Similar to steel production, Cross-Laminated Timber (CLT) is an advancement in the already successful lumber industry. The strength and reliability of timber has been tested and standardized to a finite degree and is trusted by industry professionals. Moreover, the promise of dramatic global CO_2 emissions reduction and potential for environmental reparation is a strong selling point. Finally, the widespread application of robotics and computational systems to architectural practices is a notion that is already being adopted in the field. Kevin Singh, a licensed Architect and Associate Professor at Louisiana Tech University, estimates that, based on the CLT industry in Europe and Canada, it will take approximately ten years for the technology to catch on, but it is highly likely that Cross-Laminated Timber will be adopted by industry professionals.

Conclusion

Cross-Laminated Timber

The solution that best fits criterion three is Cross-Laminated Timber. GeoPolymer concrete is not likely to be quickly adopted in the construction field, but photovoltaic (PV, or solar) electricity in steel production and Cross-Laminated Timber (CLT) are. However, PV electricity in steel production will require global legislation to ensure the standard use of PV electricity. CLT, a short sighted fix with long-lasting and widespread positive impact, is the most likely to be adopted.

17 Conclusions

After applying the three potential solutions to each criterion, I have determined that the best resolution to global CO_2 emission reduction is the third solution, Cross-Laminated Timber. Although transitioning to PV electricity sources in steel production has a number of positive consequences and the added appeal of the first interplanetary industry, CLT is produced with trusted building materials, has the potential to reverse global excess CO_2 emissions, is likely to be an economic success, and is likely to be adopted by the construction industry. The second best strategy is the use of PV electricity in steel production. It has the potential to reduce a significant amount of CO_2 emissions and has an exciting prospective economic growth, but lacks the overall impact that CLT does. I would not recommend GeoPolymer concrete as a viable option while it is still in the research and development phase. Despite a significant measurable reduction in global CO_2 emissions, the economic benefits are incalculable, and the product is not likely to be adopted. After conducting this research, solution three is concluded to be the best possible solution for reducing excess global CO_2 emissions.

18 Recommendation

In order to reduce global excess CO_2 emissions in construction materials, I recommend using Cross-Laminated Timber, or CLT. If used in less than 1% of the total global building stock, CLT has the potential to sequester, or absorb, more than the yearly global excess CO_2 emissions, which will repair earth's atmosphere. Additionally, Cross-Laminated Timber is determined to be a superior building material and is likely to be adopted by construction professionals. For future construction I recommend the use of Cross-Laminated Timber to reduce global excess CO_2 emissions in construction.

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Appendix A - Interview - Kevin Singh

For economy of time and space, this interview was paraphrased with the permission of the interviewee.

Kevin Singh

Associate Professor at Louisiana Tech University

Education
Bachelor of Science from Bal State University
Masters in Building Construction from Auburn University

Qualifications
Licensed Architect in the State of Louisiana
Member, American Institute of Architects (AIA)
LEED AP, BD+C

Professional Practice
7 years in Practice
10 years in Academia

What is Cross-Laminated Timber?
CLT is plywood on steroids. It is 2-by material glued together to create a massive panelized system to be used for walls and roofs of buildings.

Why is CLT better than standard building materials?
You wouldn't use CLT for residential, construction at this point, but when you get into larger buildings, like commercial, the modular design reduces on site construction time by a significant factor. It is UL tested and approved, and tested in the field. Also, about 10% of wood during standard wood construction is wasted becuase of warping, cupping and bowing. CLT is cut using a CNC (Computer Numerical Controlled) Router, so is very precise and specific to its placement in the building.

What are some of the economic benefits of CLT?
As CLT is used more frequently, the costs will go down and be in line with steel and concrete. Because it is a renewable resource, and essentially all forests are sustainably managed and what you cut down has already been planted somewhere else, we will never run out of the supply.

In the next year, 4.8T sq/f of building space will be constructed, and we only need about 2/3 of a percent to be constructed from CLT to absorb all the CO_2 that humans currently emit. In your professional opinion, how long do you think it might be before CLT can reach a point where 480M sq/f of building space is built each year?

It started in Europe 20-25 years ago, and they adopted it for their building codes. CLT is in our codes now, and where you could only legally build to five stories, you can build to 20. Also, Perkins + Will (architecture firm) is working with engineers on a 40 story building made of CLT. As the technology advances, the likelyhood of reaching that number increases. It won't happen immediately, but it can happen.

Assuming all three were possible and equally as impactful, which solution do you think would be most immediately adopted by the construction industry and why?

Steel is already trusted and has a lower cost, so it will most likely be adopted up front. Cross Laminated Timber snaps together like legos, so once it's trusted it will catch on quick. Concrete will probably still cost more.

It will probably be 10 years until CLT catches on in the US, but once it does, it will be big time, especially in Louisiana. Anyone can produce plywood, but CLT is a higher profit product. So steel will be adopted up front and CLT in 10 years.

Appendix B - Interview - Pasquale DePoala

For economy of time and space, this interview was paraphrased with the permission of the interviewee.

Dr. Pasquale DePoala

Howard Endowed Professor

Education
Architecture degree from Naples University, Italy
Bachelor of Architecture from Lousiana State University
Master of Architecture from Columbia University
PhD from Texas A&M

Qualifications
Licensed Architect in Italy
AIA, LEED AP

Work
17 years in Practice
9 years in Academia

Historically, economic, political and technological changes have shaped the world of architecture. What are some of those things that most dramatically shaped architecture in the past?

Modernism was defined by a number of philosophical conclusions during and after the industrial revolution. Cast Iron, steel, glass were questioned repeatedly. The I-beam, w-flange, etc. weren't there until designers committed to manipulating and modifying steel to optimize form. Reinforced concrete is one example of hybrid materials that are a testiment to the fact that designers will continually questioning every material.

What impact do you think all PV electric steel production could have on architecture and construction? Geoplymer Concrete?

Steel and concrete allow for dematerialization and use of glass. Any innovation pushes the envelop (the wrapping of a building) to new limits.

What impact do you think Cross-Laminated Timber could have on architecture and construction?

The default of capitalism is to go back to traditional forms, and architecture should push for more radical ideas. Timber competitions have aesthetic limitations. Although sustainable, it doesn't lend well to design.

Economics is a big driver in construction, but theories in Architecture have driven big moves in construction as well. Out of the three, which do you think architects are most likely to get behind, strictly from a design perspective?

Steel. The I-beam, w-flange, etc. weren't there until designers committed to manipulating and modifying steel to optimize form. Steel has been and will continue to be the primary material for designers.

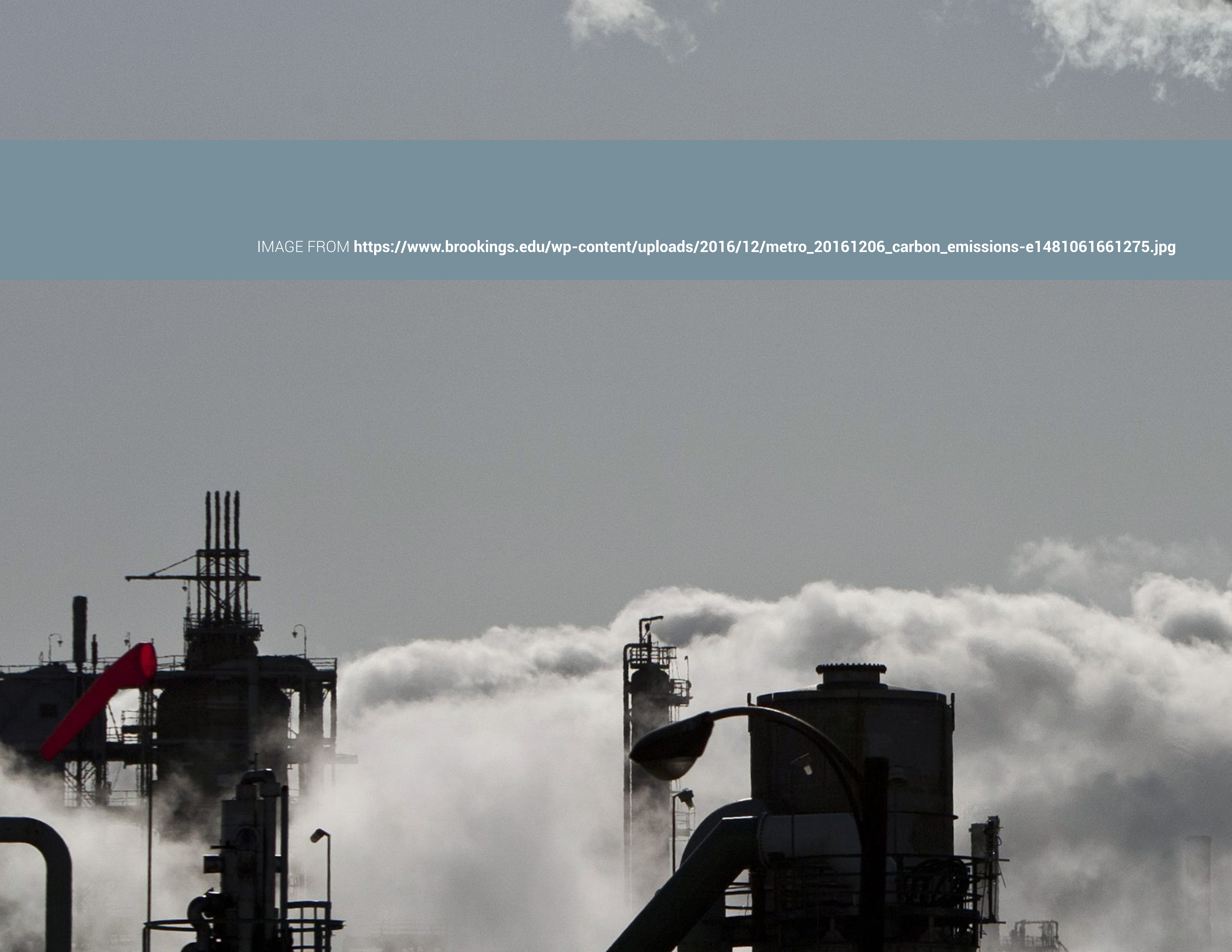

IMAGE FROM **https://www.brookings.edu/wp-content/uploads/2016/12/metro_20161206_carbon_emissions-e1481061661275.jpg**