Carbonating Concrete

Cleaning up a Virtual Polluted Mountain Valley Town using Carbon Capture & Carbon Upcycling

UN Sustainable Development Goal 9: Industry, Innovation, and Infrastructure

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Abstract

It's commonly known that countries all over the world struggle with failing and deteriorating infrastructure. Broken roads, aged electrical grids, and poor power generation solutions are just some of the issues many countries face. In addition, the number of cars on the roads continues to increase. This also contributes to the wear and tear of the roadway systems. In a lot of cases, electricity is sourced using "dirty" power generating stations (i.e., coal/oil/gas) which produce toxic fumes (pollution) all around the world. In addition, this "dirty" electricity is often transmitted through faulty power lines which can cause major problems in the future if neglected. All of these things contribute to the rising level of smog in cities as well as higher frequencies of acid rain. These showers can be devastating to everything they touch. Acid rain can also make roads and buildings crumble by weakening the concrete that makes up the majority of our infrastructure. Recent groundbreaking research has finally cracked the code on Roman Concrete: a recipe that has been lost to time for almost two millennia, and researchers have been hard at work applying modern solutions to take this ancient recipe and project it into our modern infrastructure needs. Researchers have also found that they can take carbon from the atmosphere and inject it into this concrete process resulting in stronger concrete and helping fight against air pollution. Our project takes these recent innovations, in the science space, and showcases how they could be used to better infrastructure and quality of life in a community. "Carbonating Concrete" places the viewer in a dramatized experience in which they can understand the power and potential of these technological breakthroughs. The project has been developed for the CAVE2™ Virtual Environment and allows viewers to be fully immersed in this new space, while also empowering them with how they can improve it.

CCS CONCEPTS • Human-Computer Interaction

Additional Keywords and Phrases: Roman Concrete, Concrete, Carbon Capture, Carbon Upcycling, Pollution, CO2, Methane.

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1 INTRODUCTION

Our group was tasked with developing a VR product geared towards the United Nations (UN) Sustainable Development Goal #9: Industry, innovation, and infrastructure, and through further research we were able to drill down and identify a sub-goal: Target 9.4. According to the UN Environment Program, the goal of Target 9.4 is to “upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities, [by 2030]” [9]. Therefore we found it fitting to name our project Carbonating Concrete.

Carbonating Concrete means exactly what is written, and is an embodiment of current research. Carbon Capture technologies have been created to remove pollution from the air and turn it into useful products, like jewelry. Furthermore, other research has suggested storing and/or diverting the exhaust from industry/coal power plants into kilns that bake concrete blocks with this CO2-rich exhaust. This is where our project’s name, Carbonating Concrete, originated because just like soda we’re carbonating the concrete with CO_2. Our VR project thereby portrays this very relevant research in a dramatized manner as a solution for the UN’s Sustainable Goal #9, and the sub-goal, target 9.4.

2 RESEARCH

2. 1 Problem

Many people know about the hazards of pollution in their city, state, and country, but few know just how deep-reaching the effects of pollution can be. For starters, the road to these effects begins with fossil fuel-burning vehicles and fossil fuel-burning/using power-generating plants. These mediums result in countless tons of pollution being exhausted into the atmosphere. Alone, these pollutants can be hazardous to humans and animals. However, when these pollutants mix with water in the atmosphere acid rain forms, then rains down on whatever and whoever is below this toxic cloud.

Acid rain is just as hazardous if not more so than pollution-causing mediums alone because it can affect almost everything on the earth’s surface. Paint jobs start to peel. Concrete starts to weaken. Environments and ecosystems start to change for the worse. (Some species of plants and animals can be resilient to these changes, but eventually, all levels in the food chain will be affected.) Therefore, if left unchecked this negative cycle (pumping pollutants into the atmosphere that later rains down as acid rain) can spiral out of hand. To help mitigate this, we’ve come up with a solution based on using a VR simulation environment.

2.2 Solution

Our group was able to create a dramatized VR simulation environment experience for the CAVE2™ Virtual Environment to depict and narrate a story of a user who becomes an Environmental & Infrastructure Engineering (E&IE) consultant. As an E&IE consultant the user has been tasked to learn why the infrastructure of the created VR mountain village is beginning to crumble, why certain plants are dying, and if the modern solutions of using carbon capture and carbon upcycling are enough to save it.

2.3 Additional Background (Roman Concrete)

Our real-world-based solution couldn't have been thought of without the current research done in materials science on Roman Concrete. Roman Concrete has been a mystery for almost 2 millennia due to its exact recipe never being properly recorded or shared with a trustee. As a result, most if not all modern structures have been plagued with only lasting a few decades, while certain Roman Structures have been standing for almost 2 millennia (i.e., Roman aqueducts, the Pantheon, the Roman Colosseum).

Initially, it was thought that Volcanic ash and seawater were the secret ingredients used in Roman Concrete, yet it's been found by very recent studies that Roman Concrete has self-healing properties. It was mixed with larger chunks of limestone-like minerals, and when cracks formed and water seeped through, these minerals reacted with the water to form limestone, thereby healing the concrete. Roman Concrete Piers have been found to contain a unique mineral that takes centuries to form.

Another slow timescale characteristic of Roman Concrete is that it has been found in an English Wall in England that Masons mixed calcium oxide into their concrete mixture so that it could slowly react with CO_2 from the atmosphere to form limestone [3].

calcium oxide + CO_2 = calcium carbonate (limestone).

This time scale is a bit slow for modern times, so researchers discovered that Portlandite has similar properties to calcium oxide. When it reacts with coal plant exhaust the resulting carbonation is a similar product to concrete [7].

Portlandite (calcium hydroxide) + Coal Plant Exhaust = Concrete blocks

As a result, this is the modern solution to a centuries-old problem and can be applied to be seen as a solution to the UN's Sustainable Goal #9 and Sub-Goal target 9.4.

3 IDEATION

As a result, the mystery of Roman Concrete getting solved sparked further interest in our project and showed us that our project has real-world applications/backing. This research phase helped us brainstorm some storyboards for what we wanted to happen in our VR environment.

3.1 Storyboard #1

Figure 1 was our very first rough draft prototype storyboard to quickly get some ideas down. We wanted to create a mountain valley town since having a town completely surrounded by mountains would prevent any pollution pumped into the air by the coal power plants from escaping. We initially planned on

turning off the coal power plants in favor of using clean energy wind turbines in conjunction with the yellow carbon capture tower to clean the air. However, we needed more interactions present.

Figure 1. A depiction of the first basic storyboard we created

3.2 Storyboard #2

Figure 2a depicts an updated storyboard. It's still similar to Figure 1, in terms of going along the same storyline and having limited interactions, but it's more fleshed out to make building the project during the Unity phase easier. The inspiration for having the pollution look/feel like it is depicted in Figure 2a came from Figure 2b. Figure 2b is a screenshot from "Arsenal Contemporary Art Montreal presents Cercanía by Rafael Lozano-Hemmer." [17]

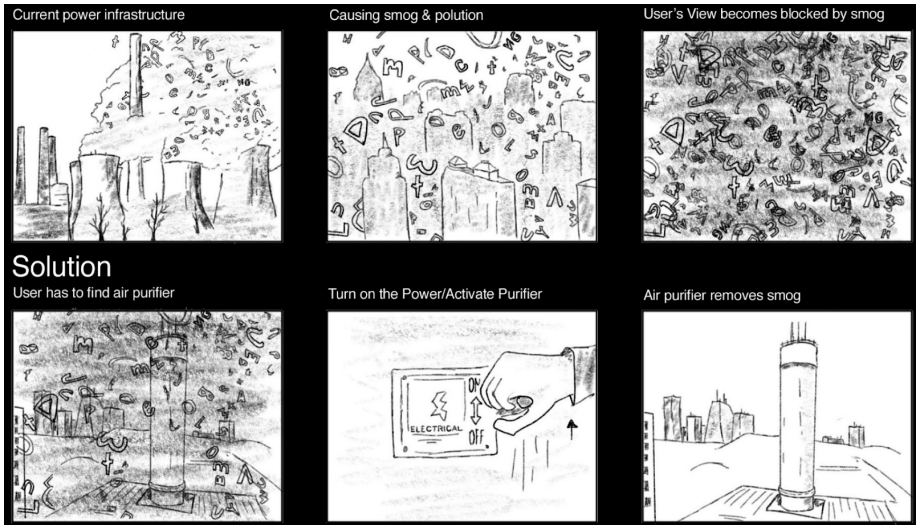

Figure 2a: Updated Storyboard sketches with inspiration from Rafael Lozano-Hemmer's Cercanía

Figure 2b: Cercanía by Rafael Lozano-Hemmer

3.3 Storyboard #3

Figure 3 shows the final Storyboard that we created to depict our 6 different interactions. 1) the user spawns outside of town in the mountains, 2) the user needs to cross a crumbling bridge but ends up in the water, 3) the user then needs to swim to the shore where he sees a kayak, 4) while kayaking along the river the user grabs nearby floating saplings and plants them along the shore and this gets completed until he reaches the carbon capture to turn it on, 5) once the carbon tower power on the pollution starts to get sucked up, and blocks start to get spit out of the tower, 6) these blocks then get put into a truck to be shipped to the bridge so that it can get fixed.

We didn't reiterate another storyboard after this one. Our story slightly changed. We removed the tree sapling finding interaction and the sapling planting mechanic for a zipline, carbon upcycling mechanic, renewable energy, and a powered train.

Figure 3: Final Project sketch, with grey-to-color after Carbon Capture tower is turned on

4 UNITY DEVELOPMENT

Unity Version 2019.2.11 was used for the development of this project. This allowed for ease of porting/building to the CAVE2™ Virtual Environment. The CAVE2™ Virtual Environment is a 360º (270º display concretion + a flat 90º wall constellation at the entrance). In addition, the sounds for this project were retrieved from EpidemicSounds.

4.1 Interactions with Typography

We believed that having too much typography would've been overwhelming for the message we wanted to convey. Therefore, we settled for using a more realistic-looking scene with typography being highlighted in select situations.

4.1.1 Crumbling Building

Typography gets emphasized here through a shaking building. There's initial wording on the side of the building that states "Degraded Structure," and once it collapses words such as rubble and destruction are present in the building place.

4.1.2 Shaking Bridge

Typography was highlighted here in the form of a crumbling bridge. The bridge shakes to simulate that it's so weak it's shaking under a single user's weight when he walks across it. The Words "Breaking Pathways" was oriented horizontally facing the user so that the user could see the words. Otherwise, if the whole phrase would've been horizontal along the bridge itself it would've been hard to read the message. As the user crosses the bridge, the phrases fall down preventing the user from crossing back. So it must get fixed for the user to cross back.

4.1.3 Carbon Tower

Typography for the Carbon tower is in the form of the actual name of the location floating above the tower. The user doesn't interact with it, except for the lever on top of the tower. When the user raises the lever the tower turns on, starts raising, and starts sucking in all the pollution into it. As this happens the color changes from gray to RGB scale. Once at the top, the vacuum sounds continue as the tower keeps sucking in the pollutants.

4.1.4 Zipline Experience

This zip line is a method created to get from the top of the tower to the next objective. We felt that this was a more creative method than using the built-in teleportation mechanic of Unity/cave2. The zipline is a short ride, and the name "zipline" follows you down the rope as a form of minimal topography.

4.1.5 Reuse Carbon

The Reuse Carbon topography is used to activate the interaction that animated the coal power plants' smoke stacks from being in a vertical position to being in a horizontal position and piping its exhaust into the cement factory. This interaction eventually triggers when the connected cities block travel across the makeshift conveyor belt and are lightly placed on top of the respective train car.

4.1.6 Use Clean Energy

The clean energy topography consists of basic typography, but it activates the interaction to animate the windmills raising up into position and the solar panels shifting into position. This also activates the sun and wind animations to show that the sun and wind are helping generate electricity for the train. Lastly, "Power Restored" is presented as our 3-D topography for this section.

4.1.7 Train Ride

The train is stuck in the station until the green flag is created out of the word flag but is in the shape of a flag. It's also green to make identification easy. The user then needs to wave the flag outside of the caboose so that the train's engineer can start the train. Once the train starts moving there's no stopping it until it reaches its destination, next to the collapsed bridge.

4.1.8 Infertile Farmland Transition to Fertile Farmland

As the train moves, the user can look off to the left of the caboose to see that the water pumps have now been turned on and that crops have started to grow once again. This is an automatic interaction triggered by the train movement.

4.1.9 Fixing the Bridge

The train stops next to the broken-down bridge, and the "connected cities" blocks automatically float into place. This time the phrase is horizontal to the bridge. This is different from the broken pathways message as the user is free to choose if they want to read the message or not.

4.2 Optimizations

The main optimization we conducted for this project was to reduce the number of polygons in our building destruction typography. This typography had ~15 million polygons while our project in total had ~17, so this single location was causing a lot of lag. We also removed unused assets from our folders, as well as applied occlusion culling to reduce the number of objects the renderer had to render. As a result of these modifications, we were able to raise our FPS to ~30 FPS.

4.3 Gray-to-Color Scale

The gray-to-color scale was thought up in the storyboard phase and then implemented during the unity phase. The gray-to-color scale uses a shader attached to a post-process script that's attached to the main camera. This allows for a full-screen effect to take place. The gray-to-color scale transition gets activated when the user activates the carbon capture tower interaction. As a result, the mountain valley town goes from a dirty and polluted-looking environment to a crystal clear and vibrant environment.

5 RESULTS

Our project was successfully created and exhibited on the CAVE2™ Virtual Environment at the Electronic Visualization Lab (EVL) at UIC where 50 people were able to give feedback over 2 consecutive testing days, and on the final demo day.

Figure 4 shows a zoomed-out point of view of our world. It's in greyscale, to emphasize the pollution and smog trapped in the mountain valley town. The exhaust from the coal plant's smoke stacks can be seen emitting CO2 into the air (central column and 2nd row from the bottom in Figure 4). Figure 5 shows the finished product of our mission. The "Broken Pathways" bridge topography was replaced with the "Connected Cities" typography. "Broken Pathways" is significant because, before the rebuilding of the bridge, our mountain valley town was riddled with crumbling infrastructure, while after the rebuilding both sides of the bridge were once again connected for a much longer duration. Hence the "Connected Cities" blocks naming.

Figure 4: Depicts the polluted Mountain Valley Town. Figure 5: Depicts our final scene with Connected Cities.

5 CHALLENGES

Over the course of our project, we encountered some challenges. While developing the zipline working with the user as animation itself was challenging, but the final result speaks for itself. Another challenge we encountered was the gray-to-color scaling only worked in one of the real 3D glasses. This was an interesting find because we initially believed that the processing/shader scripts applied to the main camera would propagate this change to the two isometric cameras when the project was built to the CAVE2™ Virtual Environment using the real 3-D engine. Therefore, was had to make sure the scripts were propagated to both isometric camera POVs to enable the proper transition from gray to color for both eyes. We also noticed a glitch or lag spike that happened in the CAVE2™ Virtual Environment. This spike occurred at an interval of 20-25 seconds and only affected our train interaction. We had to be vigilant with our storytelling for if we went onto the train at the wrong time we risked the possibility of "falling" off the train and needing to walk the rest of the way back to the now-fixed bridge. Thereby ruining our simulated VR experience. Through our hard work, we were able to eliminate these challenges to make the final product we've displayed above.

6 CONCLUSION

In conclusion, we believe that our project satisfies the UNEP Goal 9 target 9.4 sustainable goals, as it shows real-world research in a dramatized way so that we can put emphasis on the importance of finding creative solutions to carbonating concrete.

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