Understanding Supply Chain Pollution

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Abstract. This project is about how supply chain activities impact the environment, especially by looking at how consumer habits indirectly drive waste throughout a product's lifecycle. By looking at the hidden environmental effects of manufacturing, packaging, and distribution. These often ignored phases contribute to global pollution.
In this design-centered concept, the aim is to make an dynamic quiz system, which uses a creative visualization to show how consumer choices contribute to environmental harm, directly and indirectly, through a personalized digital reflection, represented as an avatar made out of trash. The goal is to make users have better grasp their role in generating waste, making the unseen effects of consumption more visible, pushing for more conscious and sustainable consumer behaviors.

Keywords: Supply chain · Pollution · Consumer behavior · Waste generation · Environmental impact · Sustainability · Lifecycle · Packaging · Transport · Product consumption · Body tracking · Digital mirror · Avatar · Unity · 3D visualization · Waste accumulation.

1 Introduction

The environmental footprint of supply chains extends far beyond visible waste, involving hidden costs tied to manufacturing, packaging, and distribution processes. Industries like fast fashion illustrate how rapid production cycles lead to substantial waste, particularly from excessive packaging in e-commerce, which frequently finds its way into landfills.

Seemingly minor habits, such as purchasing disposable water bottles, contribute to a larger waste problem. For example, a single bottle doesn't arrive alone—it's often bundled in plastic-wrapped packs, transported on pallets wrapped with even more plastic. This reveals the concealed environmental toll associated with packaging. By uncovering these layers of waste through interactive design projects, consumers can gain a deeper understanding of the wider ecological impact of their decisions, thereby promoting more sustainable habits.

2 Related Work

2.1 Data Collection

The examination of supply chains and product lifecycles is a well-established field, with frameworks like Life Cycle Assessment (LCA) serving as key tools to evaluate environmental impacts [1]. This project builds upon data from recent research in this domain to explore how consumer behaviors influence environmental outcomes, particularly regarding emissions and waste management within supply chains.

2.2 Theoretical

This project is grounded in theoretical research examining how digital interaction design can be leveraged to boost environmental awareness and promote sustainable behaviors. Ferreira et al. [4] explore how the use of transmedia storytelling within human-computer interaction (HCI) can communicate climate change more effectively, suggesting that multi-platform narratives are capable of engaging users on a deeper, emotional level. Similarly, Gonçalves et al. [2] highlight how interactive designs utilizing visual narratives can raise awareness about environmental issues, enabling users to engage with and reflect on these topics through immersive and transformative digital experiences. Along the same lines, Churro et al. [3] emphasize the impact of digital interfaces in climate advocacy, underlining the potential of user-centered design to enhance engagement and inspire eco-friendly behaviors.

These studies collectively underscore the effectiveness of digital platforms in delivering immediate, impactful feedback that encourages sustainable actions. Complementing these approaches, tools such as the Footprint Calculator [5] offer users tailored insights into their personal environmental footprint, thus fostering self-awareness and helping individuals make more informed decisions about their sustainability efforts.

2.3 Digital Object

Drawing inspiration from Universal Everything's Lifeforms [6], where user interactions influence the movement of digital entities, this project uses an avatar to represent the environmental impact of user behavior. In this project, as users engage with quizzes, their virtual waste accumulates on their reflection, turning abstract environmental data into a more concrete and impactful experience.

Fig. 1. Universal Everything - Lifeforms

3 Approach

3.1 Goal

The initial goal i set for this project was to design a quiz about the hidden environmental costs of consumer habits with a real-time visualization of the pollution caused. The real-time visualization would be the accumulation of 3D trash objects that conform to a digital skeleton that tracks the movement of the user through a regular webcam.

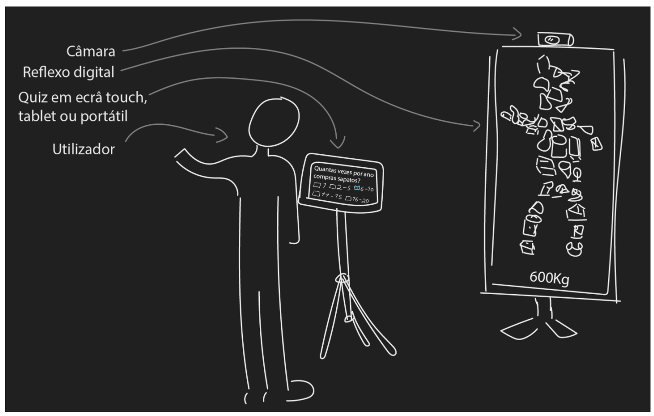

Fig. 2. Low Fidelity Mockup

3.2 Technological Implementation

Some images below are taken from my test video at https://youtu.be/L1JSLO5pwMg

Body Tracking - The body tracking system is made with Python Mediapipe. I used an open-source integration for Unity by ganeshar. After struggling with a couple of AR body tracking programs that built completely into the Unity project, I found that this Python integration worked best, although it requires a second window to be open. I really did not want to force a second window to be open, because it hinders ease of use, but under the time constraint, I decided to go forward with the solution that was working.

Fig. 3. Python Mediapipe body tracking

3D 'digital mirror' - The 3D visualization of objects with physics is done in Unity. The tracking points i picked for the digital reflection are the hands, feet, elbows, knees, shoulders, hips and head. Each time an object is generated, it picks one of these points at random and is attracted to it. In addition to this attraction force, each object has a momentum, so it tries to preserve velocity in the direction it's traveling. This results in a cool effect where objects can create orbits around the point they are tracking. The amount of objects created is just a symbolic representation of the real trash that is produced indirectly through consumption. I attempted to generate higher ammounts of objects, but the program seems to crumble under the computational demand. It gets slow and even the body tracking software starts behaving in a weird way. To compensate for this, i'm generating less object but making them bigger to fill up the space. This seems to solve the performance issues, but the program still runs slowly on computers with none or weak graphics cards.

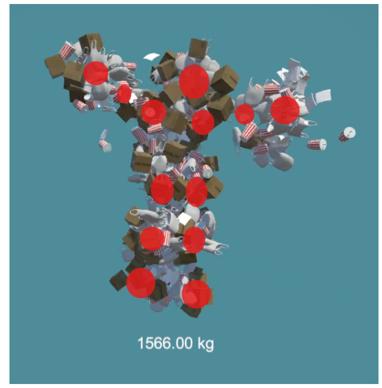

Fig. 4. 3D visualization tracking points

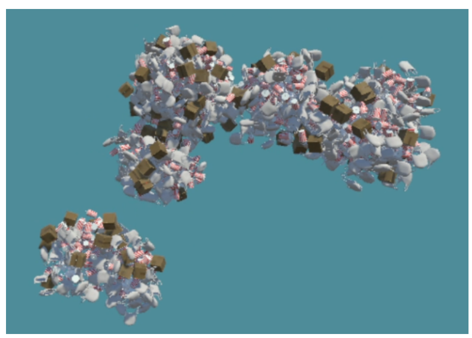

Fig. 5. Test with high amount of smaller objects - body tracking stops working

Another big issue i encountered was finding compatible 3D models. In the start, i assumed Unity would work with any 3D model that i threw at it, but this turned out not to be the case at all. In blender, you have to turn your 3D models into Prefabs to use them in a scene. Some of the models i tried using for this seemed to have a huge hitbox, compared to the mesh size. Since objects collide with each other, this would cause them to stay frozen in place, far away from the tracking points.

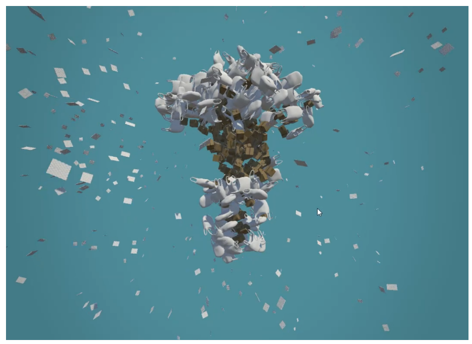

Fig. 6. Bugged 3D models

I tried editing these objects in blender, to see if there were any vertices outside of the main mesh, and even converting them into other 3D model types, but nothing seemed to fix the issue.

Fig. 7. some models tried to use without success

In the end, i was restricted to using free Unity Prefabs from the Unity asset store, which aren't very varied. I couldn't really find many good models for my goal.

I ended up with the short selection shown on Fig. 8.

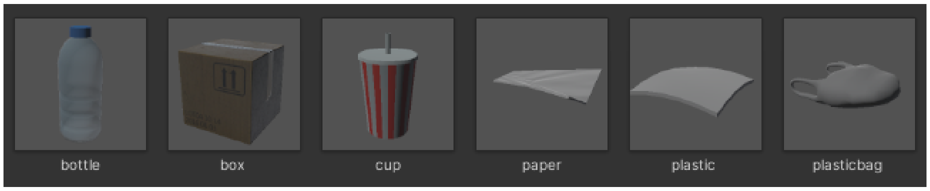

Fig. 8. List of Prefabs

Even some prefabs from the unity asset store seemed to create errors in the code. I'm not very familiar with Unity, so working around these issues was one of the biggest problems i encountered.

Finally, the unity project also displays a simple text with the total weight of trash generated, according to the user's answers. I will go into how i estimate this weight in the Quiz section.

Quiz - The quiz was made in Processing 4.3. This is a program that I'm familiar with and it can access local files with ease. Initially, I was going to develop a web UI using HTML/CSS/JS, but the issue with this is that for transferring data to Unity, I would have to run a server. To avoid this, I went with a simpler solution where I save the user answers to a .txt file. Unity then detects these file changes and generates objects accordingly.

```
6480 paper
3600 cup
3600 plasticbag
576 box
```

Fig. 9. answer file content example

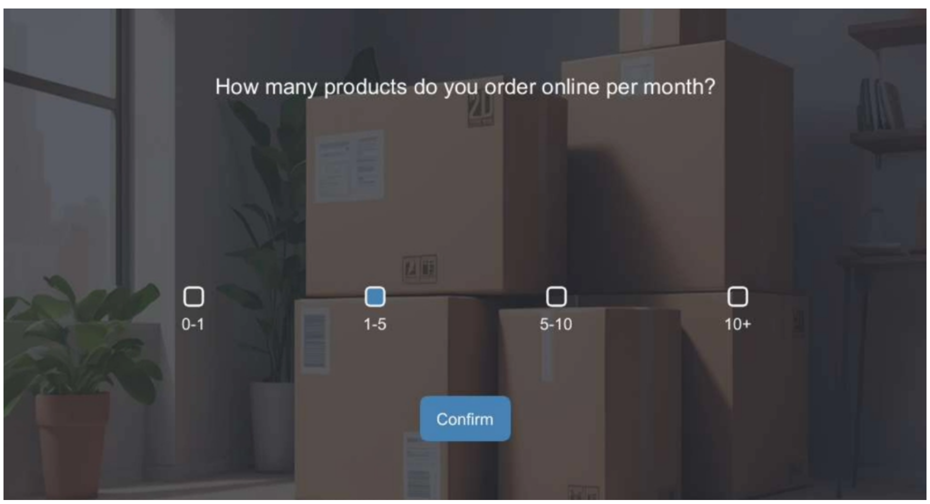

Fig. 10. Quiz

The quiz questions each have a unit value for each object to be generated. These values account for 50 years of consumption. It's best to give an example:

For the question "How many products do you order online per month?", let's first calculate the values as if the user's answer is 1 per month over 50 years. Using several online sources, I estimate that there will be at least 200 grams of cardboard and 50 grams of bubble wrap (plastic) in the packaging.

$$200 \times 12 \times 50 = 120000 \text{ grams}$$

$$50 \times 12 \times 50 = 30000 \text{ grams}$$

Lets figure out how many objects we want to generate out of that weight:

- 1 piece of paper = 10 grams of paper
- 1 cardboard box = 200 grams of cardboard
- 1 piece of plastic = 20 grams of plastic
- 1 water bottle = 30 grams
- 1 cup = 240 grams
- 1 bag = 20 grams

So, let's divide the cardboard and plastic weight by the material weight to get the number of 3D objects to generate:

$$\frac{120000 \text{ grams}}{200 \text{ grams}} = 600 \text{ cardboard boxes}$$

$$\frac{30000 \text{ grams}}{20 \text{ grams}} = 1500 \text{ pieces of plastic}$$

So the quiz will try to make Unity generate 600 boxes and 1500 pieces of plastic if the user answer is 1.

This value will simply be scaled according to the average of the user answer, so if the user answers "2-5", average being 3.5, the question value will be multiplied by 3.5.

```
HashMap<Integer, String[]> pollutionData = new HashMap<>();
pollutionData.put(0, new String[]{"4320 paper", "2400 cup", "2400 plasticbag", "384 box"});
pollutionData.put(1, new String[]{"600 box", "1500 plastic"});
pollutionData.put(2, new String[]{"2400 bottle", "516 plastic"});
pollutionData.put(3, new String[]{"37 box", "75 paper"});
pollutionData.put(4, new String[]{"3000 plastic"});
pollutionData.put(5, new String[]{"25 box", "150 paper"});
pollutionData.put(6, new String[]{"800 paper", "150 box", "45 plastic"});

float[][] answerMultiplier = {
    {0f, 1.5f, 3.5f, 5.5f}, // question 0
    {0.5f, 3f, 7.5f, 10.5f}, // question 1
    {0f, 3f, 7.5f, 10.5f}, // question 2
    {1f, 4f, 7f, 9f}, // question 3
    {0.5f, 2.5f, 4.5f, 6f}, // question 4
    {0f, 1f, 2f, 3.5f}, // question 5
    {0.5f, 3f, 8f, 10.5f} // question 6
};
```

Fig. 11. question amounts and answer multipliers

Unity will use the real weight of waste generated, but scale down the real amount of objects, as explained in the "Unity" section above, to preserve performance, not forcing the program to handle too many 3D models.

4 Experimentation and Discussion

To run tests, I connected my smartphone to the PC with a long USB cable. This serves as a touchscreen where i can view and answer the quiz. I found that the

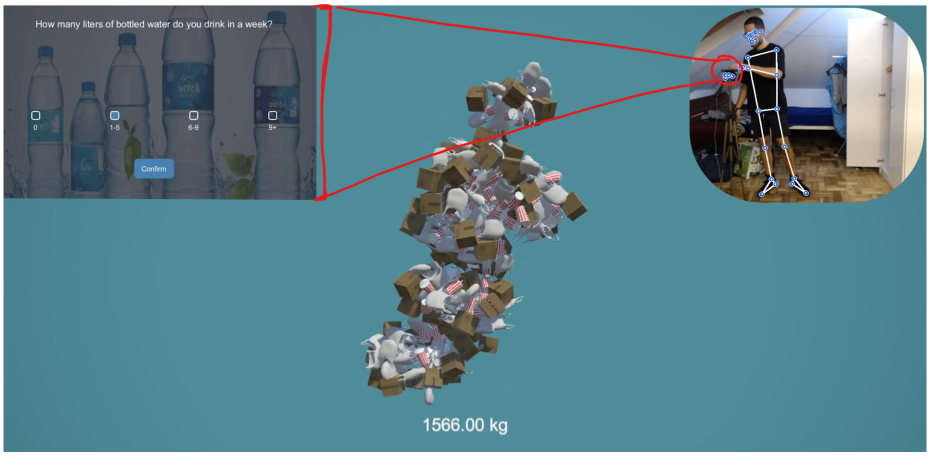

Fig. 12. Setup de Testes

body tracking works fine, although in some cases it's not very fast or precise. There were times where the tracking couldn't quite follow the exact movements the user was doing.

As mentioned in the previous section, one of the big issues with this software is the computational demand. It struggles to run on machines with no graphics card, or even with low end ones.

Something that i wasn't satisfied with near final testing was the amount of trash generated from some answers. I would like to have picked better questions, or maybe simply just more questions, so the amounts of trash generated would be a little bit more dramatic. Some answers add a lackluster or anticlimactic amount of trash to the digital reflection.

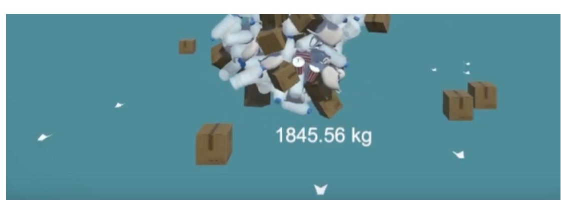

Fig. 13. Lackluster amounts of trash generated

An element that i would consider adding in the future is a visualization of the underlying structure of the skeleton in unity, something like Fig. 14. Maybe

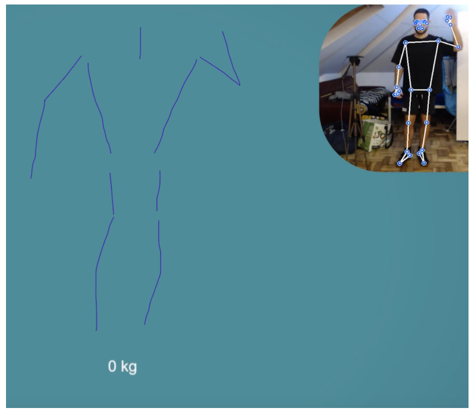

Fig. 14. Low fidelity skeleton example

the user being able to see what the trash objects are attached to would improve the feel of the experience.

As mentioned in the approach section, the number of trash units generated in unity are scaled down from the real world quantities. The model sizes themselves are also set manually. I scaled these parameters so that if a user answers with the max amount on all questions, the digital reflection will still be of a reasonable size. This max limit trash ball is hard to control because all of the objects are conflicting with each other's physics, so it mostly just moves on its own.

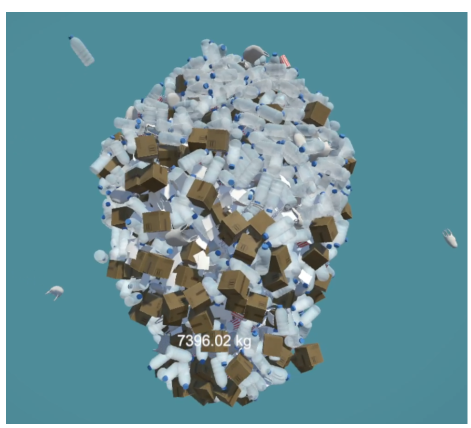

Fig. 15. max limit trash ball

5 Conclusions

This project sought to explore the environmental impact of consumer habits through an interactive, design-centered approach. By using digital body tracking and 3D visualization, the system offers users a tangible representation of the waste generated by their consumption patterns. The main goal was to turn abstract environmental data into a compelling, personalized experience that could inspire more sustainable behaviors.

Integrating multiple technologies—Python Mediapipe for body tracking, Unity for 3D visualization, and Processing for the quiz interface—despite several technical challenges, such as performance limitations, compatibility with 3D models, and computational demand, the project successfully created a functioning prototype that merges educational content with digital interaction design.

Through experimentation, it became clear that visualizing waste accumulation in real-time has the potential to enhance user engagement and provoke reflection on individual contributions to pollution. However, certain aspects aren't as refined as i would like:

- **Scalability and Performance:** The computational demand limits accessibility, particularly for users without high-performance hardware. Optimizing the physics engine and reducing resource intensity could make the system more widely usable.
- **Content Depth:** Adding more quiz questions or refining the existing ones could produce more dramatic and impactful visualizations, enhancing the emotional resonance of the experience.
- **Visual Feedback:** Incorporating a visible skeleton or structure in Unity could improve user comprehension of how objects interact with their digital reflection, making the system feel more cohesive and engaging.
- **Model Variety:** Expanding the library of 3D models used to represent waste would provide a more diverse and realistic portrayal of different types of pollution, adding to the value of the project.

Future iterations could include augmented reality features like video passthrough to the unity project or more advanced body tracking. By making invisible pollution visible and personal, tools like this have the potential to drive more conscious consumer behaviors and contribute to broader sustainability goals.

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