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The Removal Chain & Sentient Life Cycles

“The data presents a clear call for circular products and a global repairing and refurbishment culture... We must take responsibility and develop both top-down and bottom-up solutions.”

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As our cities are growing, managing waste is becoming increasingly challenging. Global plastic waste is set to almost triple by 2060 (OECD 2020) while recycling rates are staying below expectations.

At the same time, landfills are being relocated away from cities, reaching their maximum capacities, or forced to shut down due to contamination with hazardous materials. As waste management infrastructure is increasingly removed from urban areas, we are becoming further disconnected from its ubiquitous, indispensable, yet invisible life of its own.

In recent years, supply chain issues have been an omnipresent reflection of our consumerist reality. For example, when the *Ever Given*—one of the largest container ships in the world—got stuck in the Suez Canal in 2021 (Chellel et al. 2021), we were reminded that our globalized goods travel a long way around the world before they arrive at our doorstep. Still, we tend to forget that there is a life after the supply. On a planet with finite resources and growing piles of (hazardous) trash, we need to look further than the obvious. We urgently need to embrace a circular economy to combat the climate crisis. And to do so, we need to mind both the supply and removal chains.

Sentient City

At MIT Senseable City Lab, transparency is key to fostering effective change. We must unravel the inner workings of critical (urban) issues and make their underlying principles tangible for a wide audience to raise awareness and empower effective action.

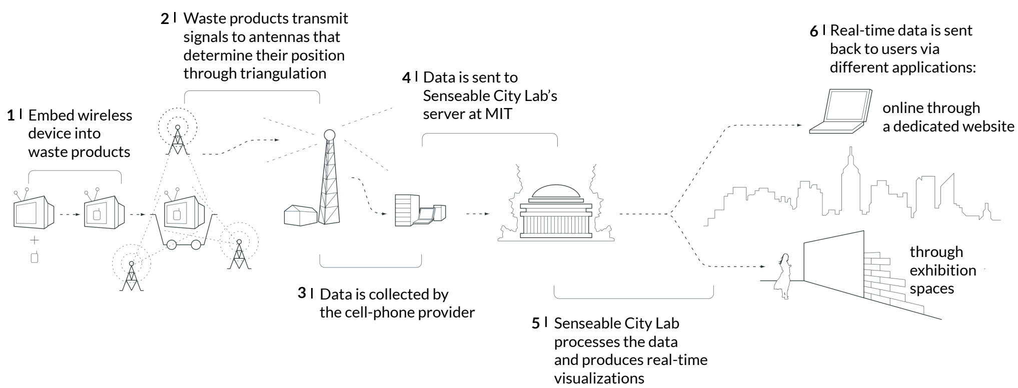
Leveraging the notion of the Sentient City (Shepard 2011) and using emerging technologies, we can simplify urban complexity and turn the city into a system that allows participation. However, unlike many ‘smart city’ ideas, we encourage an ethical, open, and transparent approach, which empowers all inhabitants to participate actively—and not only a select few at the top (Monge et al. 2022).

Confronted with the urgency of the challenges facing our growing cities amidst the climate crisis, one cannot emphasize the importance of well-functioning urban infrastructures, services, and ecologies enough. Monitoring and maintaining the health of ecosystems is crucial. One of the major issues we face in this domain is the lack of empirical data.

Trash Track

Our *Trash Track* project addresses this data scarcity (Offenhuber et al. 2013). Dedicated to understanding where our trash goes, we followed the international trajectories of around 150 end-of-life products. Our team of researchers developed a kit of sensors small enough to be hidden in household end-of-life products donated by volunteers in Seattle, Washington. The GPS tags continuously transmitted their location to us for over a month. Aggregating the newly found information with existing databases, we evaluated the environmental impact of an individual product’s *removal chain* based on the distance traveled and the type and success of end-of-life treatment and programs.

Trash Track helped analyze the effectiveness of waste removal and showed the public how the system works. The findings are accessible through maps and data visualizations on the *Trash Track* website and were exhibited in Seattle (see Figure 1 for the full project flow). The complexity and patterns of the systems suggested by the data, or the sheer movement of waste, became meaningful information for the volunteers involved in the project. They developed a strong sense of ownership and emotional attachment to the data generated by their



◁ Figure 1. The *Trash Track* ecosystem. (Credit: MIT Senseable City Lab)

donated item. The project's purpose of collecting data and facilitating discourse seemed successful. Moreover, *Trash Track* helps to understand the invisible mechanisms behind waste removal, highlights the environmental value of information in urban sustainability, and points towards possibilities for future cities.

From a global perspective, we are looking at a significantly unequal distribution of the world's waste. The data presents a clear call for circular products and a global repairing and refurbishment culture already present in the Global South. We must take responsibility and develop both top-down and bottom-up solutions, as certain policies, such as the Basel Convention's Proximity Principle, have not yet reached global vigor.

Monitour

Our project *Monitour* (Lee et al. 2017) adds another layer to trash tracking. We partnered with the NGO Basel Action Network (BAN) to investigate the flows of WEEE (waste electrical and electronic equipment), which pose environmental and health concerns. We focused on hazardous leaded glass waste from cathode ray tubes (CRT) from computer monitors and printer cartridges entering the removal chain from the US West Coast.

Many nations seek to control or prevent the inflow of waste electronic and electrical equipment. Still, such flows are difficult to track due to undocumented, often illegal global trade in electronic waste. Fraud detection amidst the vast scale of global shipping is impossible without costly audits due to very complex supply chains. Again, we applied wireless GPS location trackers to this problem, detecting potential cases of non-compliant recycling operations in the United States and the global trajectories of exported electronic waste. Our findings are accessible through the *Monitour* web application (Figure 2), allowing users to interactively follow the global trips of all tracked waste and the journey of individual items.

Monitour shows how location tracking enables new ways to monitor, regulate, and enforce rules on the international movement of hazardous electronic waste materials and highlights today's challenges and limitations of such methods.

Perspective

Now, what can we learn from these examples? What role can bottom-up tracking systems and tangible knowledge transfer play in fostering systemic change? What are other possible areas of application?

The building industry contributes 38% of global emissions (UN EP 2020) as well as 30% of global waste output (OECD 2020)—all while the building stock is predicted to double by 2050 (UN DESA 2018). To fight the climate crisis, a systemic transformation of the industry is vital (Rockström and Klum 2012; Meadows and Wright 2018). Instead of short term-thinking and profit-driven limited liabilities, we need to transition to a holistic Sentient Life Cycles system that allows us to look at supply and removal chains and everything in between.

Buildings could become material banks and store carbon (Churkina et al. 2020) and their materials' economic value over time. When building with timber—or other regenerative materials—at an urban scale, it will become more and more interesting to account for the elements and materials we have in our buildings. This knowledge would allow us to change building configurations as we investigate more lightweight, modular building construction. In addition, such data will be critical when trying to govern a necessary future carbon tax.

If sensors can track waste, why should they not track key parts in future buildings? Bottom-up technological solutions could add value by drastically increasing the granularity of the available data to inform Sentient Life Cycles. For example, smart dust could help track circular value chains, Visual AI could help catalog building stock, and machine learning could help determine the footprint of our future buildings based on the data collected.

Fostering transparency is vital for raising awareness, actively engaging citizens, and ultimately driving policy change. Gaining an in-depth understanding of where components of our buildings come from, where they are stored, and where they go next is critical information for a successful circular economy within the building industry.

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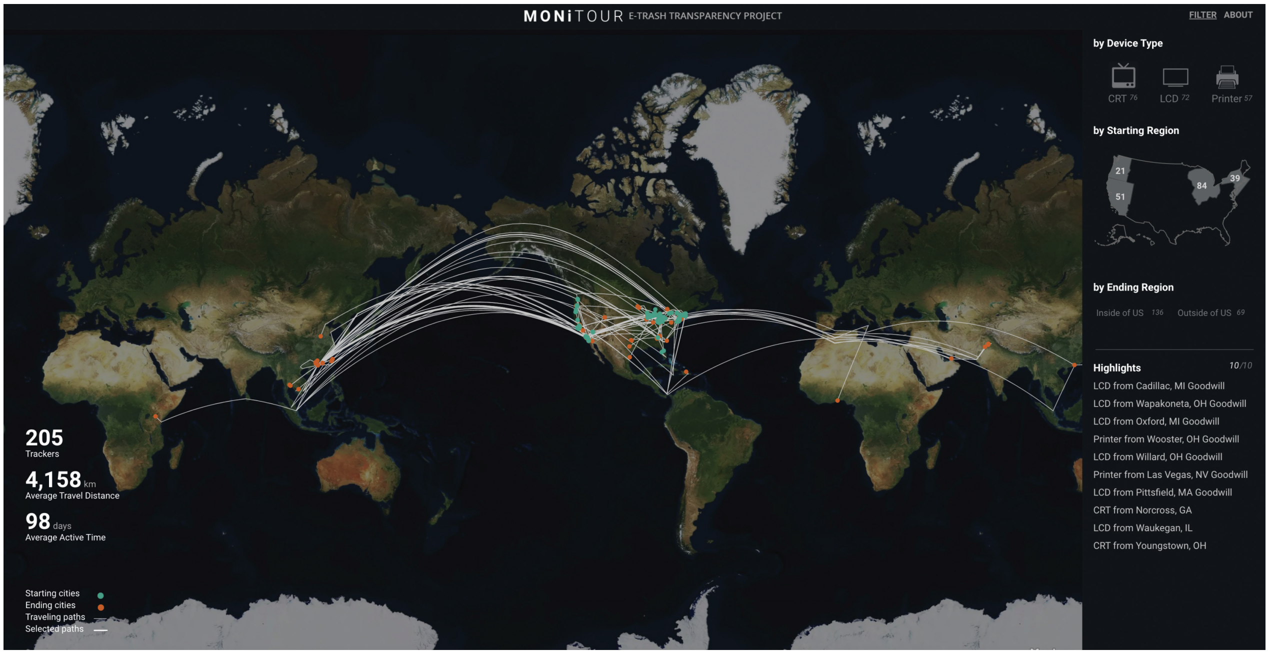

△ Figure 2. Interactive e-trash transparency on the *Monitour* website. (Credit: MIT Senseable City Lab)

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