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System Design for Solid Waste Reuse: Fostering Sustainable Urbanism through the ReUseLink system

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ABSTRACT:
This paper identifies three levels at which urban solid waste is generated: individual disposal of old objects, home renovations, and urban renewal projects. The increasing solid waste stream contributes to landfill use in rural and metropolitan areas, diminishing their ability to provide crucial ecosystem services to the city. To address this issue, qualitative research was conducted using project-based and design-thinking research and development methods. The paper presents solid waste generation and treatment research and develops a systemic behavioral, logistic, and digital solution. An online system connects municipal authorities, residents, and those interested in reuse, managing waste-producing processes, identifying the point of waste generation, and enabling logistical solutions for reuse. Emphasizing time management and object mapping, the system operates under the circular economy concept, generating financial and environmental profit. Furthermore, the system integrates waste management into the planning stages of renovation or renewal projects, allowing for proactive waste management considerations.

Keywords: Sustainable system design, Sustainable Development, Twin Transition, New Urban Agenda

1. Introduction

Urban solid waste in the EU - The use of landfills in the EU has reduced from 24% of total municipal waste in 2017 to 18% in 2020 (Directorate General for Communication, 2018). However, this progress still falls short of the EU Landfill Directive (The European Parliament and the Council of the European Union, 2018), which aims to achieve a landfill rate of 10% or less by 2035. Additionally, the World Bank estimates a global increase of 73% in waste generation from 2020 to 2050 due to population growth and urbanization (The World Bank, 2022), making meeting this goal more challenging.

The Waste Framework Directive of the EU (European Parliament, 2018) establishes a preferred treatment hierarchy for waste management, with prevention being the highest priority, followed by reuse. To facilitate this hierarchy, several measures are recommended, including maximizing the use of waste as secondary raw materials, implementing efficient waste separation systems, leveraging economic incentives and business models, and promoting public education for reuse (Ladychenko, Melnychuk, Golovko, & Burmak, 2020).

SDG11 - Sustainable Development Goal 11, part of the United Nations' Sustainable Development Goals, focuses on creating inclusive, safe, resilient, sustainable cities and human settlements. Urban solid waste generation poses significant challenges and opportunities for sustainable urban development. Rapid urbanization and population

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growth have led to increased waste generation, contributing to environmental pollution, health risks, and resource depletion (Sharma, et al., 2021). Effective waste management systems, including waste reduction, recycling, and proper disposal, are crucial for building sustainable and resilient cities. Implementing integrated waste management strategies, such as the one proposed in this paper, promoting circular economy principles, and adopting innovative technologies, can minimize waste generation, enhance resource efficiency, and contribute to achieving the targets of SDG 11 (Ramakrishna & Jose , 2021).

UN-Habitat's New Urban Agenda, adopted at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III) in 2016, provides a global framework for sustainable urban development. It outlines a vision for inclusive, resilient, sustainable, and equitable cities and human settlements. The New Urban Agenda recognizes the crucial role of cities in achieving sustainable development and addresses challenges such as poverty, inequality, climate change, and rapid urbanization. It emphasizes the need for integrated and participatory urban planning and management to create inclusive and sustainable communities (Acioly, Vignol, & Jonsson, 2020).

The New Urban Agenda defines solid waste management as a pillar of sustainability, expanding the urban perspective to a metropolitan one. It supports decentralized decision-making on waste disposal to promote universal access to sustainable waste management systems. The proposed system in this paper draws competencies from decentralized actors and embraces a circular economic perspective (Nogueira, Ashton, & Teixeira, 2019). This interlinking of the Twin Transition and the New Urban Agenda forms the primary system theory of the proposed solution, recognizing three levels of urban solid waste generation: individual disposal, home renovations, and urban renewal projects.

Landfill use hampers the ability of rural areas to provide ecosystem services to cities (Vaverková, 2019). These services include food production, water supply, rain absorption, climate control, oxygen supply, and cultural services such as recreational and spiritual benefits. In line with the New Urban Agenda, landfill reduction requires shifting from a city-centric to a metropolitan perspective. Urban municipalities must adopt a metropolitan system perspective that recognizes the interconnectedness of cities and rural areas within a region, promoting integrated, efficient, and sustainable approaches to urban waste management. This approach fosters regional cooperation and governance of waste.

Twin Transition of Decarbonization and Digitalization - Two ongoing mega-transition processes are the transition to a digital world and a green economy. Ideally, these transitions support each other. This Twin Transition is a foundational concept in this research and is utilized to reduce solid waste by promoting reuse practices. The waste treatment process in the EU alone was responsible for 150 million tons of carbon emissions annually in 2017 (Eurostat, 2020). The Twin Transition within the context of urban waste generation in the EU refers to the simultaneous pursuit of a circular economy and digital transition. It emphasizes integrating sustainable resource management practices with digital technologies to optimize waste processes (Fouquet & Hippe, 2022). The circular economy transition focuses on minimizing waste generation, promoting waste

separation, and implementing efficent recycling and recovery systems (Lahti, Wincent, & Parida, 2018). The digital transition involves leveraging sensors, IoT devices, and data analytics to monitor waste generation and enhance resource allocation. The EU promotes this approach to achieve sustainable and resource-efficient waste management, fostering a resilient and environmentally friendly urban waste system.

In conclusion, addressing wicked sustainability problems such as solid waste and landfill reduction requires complex solutions composed of human and cultural aspects along with technological ones. In his article, The Tragedy of the Commons, Garrett Hardin discusses the existence of problems that do not have a straightforward technological solution. While technological advancements are important, it is essential to recognize the significance of human-centered approaches in addressing such problems (Hardin, 1968). The development of the ReUseLink system represents a human-based solution where technological solutions complement and enhance its effectiveness. By emphasizing cultural and human foundations, we can lay a strong groundwork for sustainable practices and address the wicked sustainability problems associated with solid waste management.
This literature review highlights the importance of addressing urban solid waste generation through sustainable waste management practices and promoting reuse. It underscores the need for integrated approaches, international frameworks, and the synergistic integration of digital technologies. By implementing comprehensive waste management strategies that align with sustainability goals, cities can mitigate the environmental impact of waste generation and contribute to building resilient and sustainable urban environments.

2. Research method

The research employed a human-based qualitative approach, utilizing project-based and design-thinking methods to develop innovative systemic solutions for the complex challenges of urban solid waste. The method involved a multidisciplinary, iterative process combining design thinking and scientific research. It commenced with a comprehensive literature review and employed various qualitative data collection methods such as interviews, observations, participant observation, prototyping, and simulations. These methods provided valuable insights and informed the design of the ReUseLink solution.

Close collaboration with stakeholders, including architects, municipal management, community members, and artisans, was practiced throughout the solution development process. This collaborative approach ensured a deep understanding of their needs, aspirations, and constraints, facilitating co-creation and ensuring the practicality and relevance of the proposed solutions. To gather further insights, five observations, six field outings, and eight interviews were conducted as part of the design research. In one of the prototypes, a presentation outlining the mission and functionality of the ReUseLink system was shared with several stakeholders. Subsequently, interviews were conducted to gauge the system's relevance to their work and the level of engagement they anticipated from their clients.

The second prototype, conducted in collaboration with interior designers, tested the ReUseLink process during a three-month home renovation project. The testing phase encompassed activities such as mapping reusable objects, online sharing and acceptance by interested individuals, careful dismantling, and ultimately distributing the reclaimed items to those who claimed them. These research methods and prototypes were instrumental in gathering feedback, evaluating participant engagement, and refining the ReUseLink solution to ensure its effectiveness and practicality in addressing urban solid waste challenges.

3. Design Research Findings

The design research examines various aspects related to waste management and reuse patterns. One key finding is that the authorities' prompt collection of solid waste on the street is crucial to avoid being perceived as negligent. However, due to the authority's policy for quick clearing, there is a lack of substantial logistics and time, which hinders the possibility of reusing these materials. The study also highlights challenges faced by websites dedicated to promoting reuse and waste disposal, including difficulties in reaching physical locations immediately, inaccurate product descriptions leading to transport or preparation problems, and user reluctance due to uncertainty and the need for spontaneous action. Another significant finding is that renovation contractors prioritize minimizing dismantling time and costs, resorting to aggressive dismantling methods that make reuse impossible. The contractors and the authority aim to reduce construction skips' duration in the public domain to mitigate accumulated costs. However, full construction skips make sorting and reuse challenging, limiting potential users' exposure to these materials. The study also identifies organized "waste pickers" teams in larger urban renewal areas who salvage valuable raw materials, sometimes unofficially and with silent cooperation. This conduct poses safety problems at the sites and prevents their opening, thereby restricting access to products and additional raw materials for other users. These findings illuminate the complexities and obstacles surrounding waste management and reuse practices.

4. Research and development of the ReUseLink

The ReUseLink system, developed through human-based design research, addresses the challenge of solid waste reuse. It focuses on the crucial resource of 'time' required for reuse preparation tasks. By early identification of waste formation and utilizing predictive behavior patterns, the system generates time, enabling efficient reuse processes. It offers tools for resource management, team planning, inventory prevention, task assignment, and data analysis to increase the reuse of products, objects, and raw materials. Thus, it aligns with the EU Waste Directive's goal of preparing for reuse.

Object detachment - The research emphasizes the emotional, physical, and technical aspects of the moment when an object transitions from a beloved possession to trash. It identifies a behavioral pattern in people's relationship with their possessions, including an emotional detachment process and physical separation as objects become waste. This

point of separation provides an opportunity for intervention and action to prepare objects for reuse.

The study reveals that people connect strongly with objects based on emotions, lifetimes, and associated events. Unique use or repair cycles and hand-made personalized objects further strengthen these connections and extend the duration of object use. Understanding the detachment process helps identify timeframes in which objects begin to transition to garbage, offering improved potential for reuse.

The authorities - Intervening in the detachment phase is crucial for reducing solid waste volume, but it requires complex logistical processes. Authorities strive to minimize the time waste that remains on the street, implementing policies for timely removal and coordination. However, building a reuse-focused logistics infrastructure requires additional time for actions such as mapping, measuring dimensions and weight, and determining physical conditions. Controlled disassembly and transportation to repair or renovation facilities may also be necessary. These operations are essential preparation steps for reuse.

Adding the large-scale projects - The need for more time for reuse preparation becomes more critical in scenarios generating a larger volume of waste, such as citywide property renovations and urban renewal projects. Contractors often prioritize quick dismantling and removal, sometimes employing non-expert teams or heavy machinery without reuse considerations. This approach poses safety hazards and hinders the exploration of all potential options for dismantling and evacuation.

Economic and environmental aspects - Economically, reducing dismantling and transportation costs to the landfill incentivizes stakeholders. Prototyping, involving personal detachment, contractor and architect workflows, and interactions with homeowners, explored emotional, logistical, financial, and environmental aspects within a complex system. The aim was to create a circular economy that benefits all stakeholders financially and environmentally.

One apartment renovation prototype demonstrated significant savings of approximately 27% (€2,200) compared to the dismantling and removal bill of €8,150. Municipal authorities will benefit from reduced removal and landfill costs, along with the opportunity to coordinate reuse collections for people in need. Homeowners experience lower removal costs and find it easier to separate from emotionally charged objects. Contractors profit economically by reducing evacuation volume, especially in light of stricter regulations, increased transportation costs, and landfill distances.

Additionally, the ReUseLink system contributes to decarbonization by facilitating reuse and reducing solid waste volume. The prototype alone saved an estimated 5,167 kg of waste without considering the emissions savings from decreased transportation. Overall, the ReUseLink system offers a comprehensive solution for enhancing solid waste reuse, benefiting various stakeholders while promoting sustainability.

Competitive analysis - Throughout the research, it has become evident that there are numerous participants in this complex ecosystem. These participants can be broadly categorized into two main groups. The first group comprises companies or organizations that handle used merchandise, such as repair cafés, the French company 'Cycle Up,' or municipal recycling centers (Timm-Bottos, 2018). These entities typically possess substantial warehouses where items are stored until a request for them is received. In contrast, ReUseLink operates on the principle of directly moving items to their intended destination without needing a storage facility. The second group comprises online platforms that facilitate the sharing of a vast array of items found on the streets or about to be discarded. Multiple sharing and selling online platforms were examined during the study, and it became evident that their weakness was spontaneous and small-scale activity. Furthermore, these platforms often lack detailed information regarding the item's measurements or overall condition.
In response to this, ReUseLink shares items on such platforms and others, aiming to encourage users to claim these items. However, ReUseLink does so by providing a comfortable timeframe for item pickup and ensuring that the item will be available as promised on the agreed-upon day.

5. The ReUseLink

Characterization of ReUseLink - The ReUseLink system aims to establish a logistical infrastructure that promotes the reuse of solid waste, aligning with sustainable development goals and the EU Landfill Directive's target of less than 10% waste landfilling in Europe by 2035. ReUseLink is conceived as a dynamic and scalable system capable of adjusting its operations based on the specific characteristics of the local waste stream and the geography of its implementation region. The fundamental principle guiding its feasibility is lean management, eliminating the need for a waste storage facility and reducing costly transportation and landfill usage. Instead, the system establishes connections between products in the Pre-waste stage and their prospective users. This paper elucidates three scales of operational scenarios, demonstrating the system's versatility in localization. 1) mental and physical detachment from individual objects, 2) complete apartment renovations, and 3) urban renewal processes. Dedicated logistics are tailored to each scale, all with the goal of expanding the reuse of items before they become solid waste.

The 'three scales' approach provides intervention points in the detachment process, enabling waste formation forecasting and extending the time available for preparing products for reuse. This includes tasks such as geographic mapping, repairs and adjustments for reuse, marketing to interested users, and direct transfer to new homes without needing temporary storage facilities.

In addition to the personal detachment process from objects that leads to more waste in landfills, other and larger processes create much larger volumes: Minor and whole apartment renovations, for example, involve the removal of waste to temporary construction skips near the site. These processes are typically managed by architects or

designers over several months, involving the creation of demolition and construction plans. On the other hand, urban renewal projects span several years and involve numerous individuals, generating a significant volume of solid waste. During the planning and execution stages of these projects, a substantial period exists that can be optimally utilized for product mapping and disposal, involving collaboration between designers, property owners, and other stakeholders. This allows for the production of a bill of quantities for the waste, enabling the early establishment of the necessary logistics for reuse, even before the actual work begins.

In summary, the ReUseLink system strives to establish an effective logistical infrastructure that facilitates solid waste reuse. Targeting detachment processes and incorporating different scales of projects maximizes the time available for preparing items for reuse, contributing to the reduction of landfill waste and supporting sustainable development goals.

Object Scale - Detachment from an object and its turning into solid waste begins long before it is thrown on the street. However, when the object is put into the public domain, the local authority rushes to vanish it into landfills. This project calls on the authorities to take responsibility for the reuse processes and offers operational and economic tools for implementation. Below are the stages of project implementation in the three standards.

- A requirement of the local authority to upload details to a website before the waste is thrown away. At this stage, the object will wait a few days for someone to demand it before it goes out as waste to the street.
- During the online sharing days, other interested parties could plead the object for themselves and coordinate collection through the same digital platform.
- The authority can carry out the transport itself since it has to remove the object in any case, only it transfers to a new owner instead of transferring it to a landfill.
- This solution increases the number of new and existing stakeholders who can reuse. Also, such a move optimizes the process by direct delivery without holding the object at storage.

Home Renovation Scale - Furniture, household goods, and scrap waste are generated on this scale. The impact depends on the ability to identify significant sources of waste, preferably on a larger scale, as in the previous section. Work steps:

- The planning phase begins with mapping the waste expected to be generated during the replacement and demolition of elements in the construction. Particular focus will be placed on raw materials and objects adequate for reuse.
- The mapping of products and raw materials will include - dimensions, conditions, required repairs, and photos.
- Uploading the details to the website to expose the products to interested parties such as renovation contractors, housing improvers, designers, artists, and sustainability centers.

- People who choose a product will commit to dismantling and transferring it according to the expected schedule, which will be determined in coordination with the project management.

Urban Renewal Scale - This scale creates an enormous volume of solid waste. Here, another separation process can be leveraged to increase the amount of waste transferred for reuse and other treatment. In this case, a planning phase of several years, along with accompanying the tenants by the developer, the contractor, and the municipal authority. Here, there is a long separation process that allows for mapping and preparation for reuse in larger volumes, and, again, the sharing of the products mapped on a dedicated website enables relevant players to demand the products ahead of time. The presence of various types of professional teams on the construction site can also increase the range of products that can be disassembled for reuse, and even more so if the dismantlers are the ones who will use the products in the future and have an interest in gentle and professional dismantling. Unlike the intermediate scale of a renovation, here, there is a need for a professional dismantling contractor and a dedicated utility container onsite that will be used by the dismantling team and will also be used as the place from which the products will be transferred to their reuse.

- A crucial part of the success of ReUseLink in this scale is mastering complex logistics based on accurate knowledge of the condition of the products in the field. Steps:
- Since the entire building is planned for demolition, there is no need for the planning stage, and it is possible to go straight to the documentation of the products by scanning in a dedicated application and photographs along with accurate measurements.
- Activating a scheduling management system to coordinate dismantling and evacuation will improve control and reduce landfill waste.
- Managing the disassembly and delivery allows the various interested parties committed to the online platform to come and collect the products within a specified time frame.

Barriers to Implementation and Scaling-up - Two barriers were identified during the development process that may require further attention during the scaling-up phase:

Firstly, there is a challenge in influencing the behavior of municipal authorities when it comes to logistics associated with moving objects from one private home to another. Currently, the same amount of logistical effort is invested by municipal authorities in transporting objects to landfills. Overcoming this barrier involves effectively communicating the benefits of redirecting objects for reuse instead of disposal and encouraging collaboration between municipal authorities and the ReUseLink system.

Secondly, the success of ReUseLink is intricately tied to its ability to navigate diverse regulatory and legal frameworks, which vary across local authorities. These regulations encompass aspects such as waste disposal protocols, liability considerations, and privacy concerns related to sharing personal information on the online platform. ReUseLink has established a straightforward rule to manage this complex system

effectively: the primary beneficiary at each scale of operation assumes the responsibility for addressing the corresponding regulatory landscape. For example, at the single-object scale, the municipality serves as the primary beneficiary. Consequently, it safeguards user privacy, manages liability issues, and oversees logistical aspects. In contrast, at the Urban Renewal scale, the contractor assumes the role of the primary beneficiary and is responsible for navigating and addressing the relevant regulations. This systematic allocation of responsibilities ensures a targeted and effective approach to regulatory compliance tailored to the specific operational scale within each local authority. These identified barriers highlight the challenges that must be addressed to implement the ReUseLink system on a larger scale successfully. Acknowledging and proactively addressing these barriers makes it possible to overcome the obstacles and maximize the system's potential for sustainable solid waste management and reuse practices.

Regarding the potential of ReUseLink to expand, it is contingent upon contractors and municipalities embracing the behavioral approach outlined in this study. If this approach is adopted, the applicability of ReUseLink could extend beyond its current scope to encompass other projects, such as the refurbishment of public buildings or the renovation of office spaces. In the context of rapidly developing urban living, numerous operations generate reusable waste regularly, including theaters and trade show centers. Various target audiences, such as designers, artists, or the general public, can utilize this waste. As the AI revolution progresses, targeting specific audiences will become increasingly efficient, thereby facilitating more effective resource management.

6. Conclusion

This paper presents a system design for solid waste reuse that addresses the challenges of urban solid waste generation and aligns with the goals of the Twin Transition model, SDG11, and the UN-Habitat's New Urban Agenda. The research conducted a comprehensive literature review highlighting the importance of sustainable waste management practices, circular economy principles, and digital technologies in reducing waste generation and promoting reuse.

The ReUseLink system, developed through human-based qualitative research and design thinking methods, offers a systemic solution to manage urban solid waste. The system focuses on time management and object mapping, integrating waste management into renovation and urban renewal projects. By connecting municipal authorities, residents, and interested individuals through an online platform, the system facilitates the identification of waste generation points and enables logistical solutions for reuse.

The successful implementation of the ReUseLink system relies on inducing behavioral changes among municipal authorities and individuals. Through design research and co-design methods, the research identified a combination of regulations, incentives, and educational programs currently utilized by authorities to influence behavioral norms, provide motivation, or enforce regulations related to solid waste management. The ReUseLink system enhances the efficiency and changes the mix of the existing toolkits by

introducing novel value propositions during the liminal phase, just before products are discarded onto the streets as waste, and through employing a higher level of engagement.

One of the value propositions of ReUseLink is the improvement of the quality and efficiency of community engagement strategies around urban solid waste. According to the seminal 'Ladder of Citizen Participation' by Sherry Arnstein (Arnstein, 1969), most interactions between authorities and individuals around solid waste observed in the research could be located in the low levels of 'Nonparticipation' and 'Tokenism.' The ReUseLink employs strategies based on concepts of 'partnerships' and 'delegation of power.' Moreover, the Circular Economy concepts of localized, sustainable, and just value generation may improve the system's longevity. The design research findings emphasize the significance of addressing emotional and human aspects of waste management, which emerges as a potential catalyst for sustained participation and support. The detachment process between individuals and their objects is crucial in determining the potential for reuse. By intervening in this phase and creating capacity for reuse preparation, authorities can effectively reduce the volume of solid waste. The Waste Framework Directive (Directorate General for Communication, 2018) defined a hierarchy of actions for preventing waste in general, especially using landfills as a last resort: moving from 'disposal' to 'recovery,' 'recycling,' and 'preparing for re-use.' ReUseLink addresses this call for action, providing policymakers with a system dedicated to 'preparing for re-use' of solid waste such as furniture, which constitutes 42% of bulky waste in the UK (European Environmental Agency, 2018). The research also highlights the economic and environmental benefits of the ReUseLink system, including cost savings and reduction in carbon emissions. ReUseLink is based on the three principles of circular economy: design out waste, keep products and materials in use, and regenerate natural systems. Circular economy principles have been acknowledged as a main vehicle for the decrease in landfilling and reduction in the use of raw materials (Lieten, 2018) (OECD, 2020).

The analysis of the research and development of ReUseLink has culminated in the identification of three key steps that policymakers and industry professionals can adopt to drive behavioral change in the context of solid waste reuse: 1. Engage in Dialogue: Open communication with individuals is a powerful tool for driving behavioral change and boosting solid waste reuse. 2. Reshape 'Preparation for Reuse': Shift from only focusing on aiding those in need to involving individuals who can invest in the repair process, enhancing the efficiency of the 'preparation for reuse' stage. 3. Empower System Impact Stakeholders: Policymakers should motivate professionals like contractors, architects, and designers to spearhead waste reduction efforts, acting as influential change agents in the industry.

The proposed system aligns with the principles of the Twin Transition, which emphasizes the integration of circular economy practices and digital technologies for sustainable resource management. By adopting this approach, cities can minimize waste generation, enhance resource efficiency, and contribute to achieving the targets of SDG11 and the UN-Habitat's New Urban Agenda.

In conclusion, this paper demonstrates the importance of holistic and integrated urban solid waste management approaches. By considering the human, cultural, and

technological aspects, the ReUseLink system provides a comprehensive solution for solid waste reuse, contributing to sustainable urban development and reducing landfill use. Implementing such innovative systems and embracing circular economy principles are crucial steps toward building inclusive, resilient, and sustainable cities and human settlements.

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