A prototype information system for managing and pricing e-waste

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Abstract

There is no doubt that innovation drives development in all areas of human activity, including electrical and electronic equipment. However, the production of new equipment has a significant impact on the natural environment and a relatively high consumption of natural resources. To address these issues, the circular economy has been implemented in recent years by promoting and introducing numerous measures to facilitate the recycling of used goods. However, it has been found that there are many obstacles and difficulties currently faced by decision and policy makers. In this paper, we try to fill the research gap by presenting the prototype of an information system (IS) that could help not only these stakeholders, but also other interested parties, to move towards a circular economy through the efficient management of used electrical and electronic equipment (e-waste). In this context, we present the prototype of the system and elaborate on its two main components, namely functionality and user interface. Furthermore, we discuss the future research directions regarding the development of existing and new system features, followed by a comprehensive usability testing.

Keywords: Prototype, Information System, Used Electrical and Electronic Equipment, E-waste, Circular Economy

Introduction

The circular economy (CE) is a system in which materials never become waste (Soto Bermudez 2020) and nature is regenerated (Beers 2022). In such an economy, products and materials are kept in circulation through processes such as composting, maintenance, reuse, remanufacturing, refurbishment and recycling (Geissdoerfer et al. 2017). In this way, the circular economy addresses the global issues of climate change (Yang et al. 2023), biodiversity loss (Esposito et al. 2020), waste and pollution by decoupling economic activities from the consumption of finite resources (Zhu et al. 2019). More broadly speaking, the CE holds particular promise for achieving several Sustainable Development Goals (SDGs), including SDG 6 on energy, SDG 8 on economic growth, SDG 11 on sustainable cities, SDG 12 on sustainable consumption and production, SDG 13 on climate change, SDG 14 on oceans and SDG 15 on life on land (United Nations 2018).

However, there is no easy way to implement the circular economy in today's society. The barriers that have emerged most frequently concern technological, political and regulatory, financial (economic), managerial, performance indicators, consumer and social factors (Galvão et al. 2018). Since access to information plays a central role, individually and collectively (Webster 2014), economically and socially (Mupinga and Maughan 2009), one possible way to address these barriers is to provide effective information systems (ISs) (Demestichas and Daskalakis 2020). Indeed, there have been considerable endeavours undertaken to design and implement ISs in many different areas, including quality control (Baran et al. 2021), logistics (Makarova et al. 2021), organizational performance (Khan et al. 2021), supply chain management (Ying and Li-jun 2012), waste management (Szafraniec 2017), just to name a few.

While current research streams have focused on specific domains and have considered user information needs in a narrow way, to the best of our knowledge, few recent studies have considered information system requirements for used electrical and electronic equipment (UEEE). **The goal of this paper is to discuss selected aspects related to the management and pricing of UEEE**. In particular, we aim to outline the rationale behind the use of information systems in the exchange of such goods by reviewing the state of the art literature. In this regard, we also present the progress of our research efforts with respect to the first prototype developed. To achieve these objectives, this study adopts a qualitative approach to explore the topic of interest (Bengtsson 2016), as well as taking advantage of the well recognized a case study approach (Tellis et al. 1997).

The rest of the paper is organized as follows. Section 2 outlines the rationale and background of the study. Section 3 presents the concept of the information system for e-waste management, while Section 4 expands on potential future research directions.

Background and Rationale

From a global perspective, the electrical and electronics market is an industry synonymous with innovation and continuous development. Encompassing electrical appliances, measuring and control instruments and a vibrant range of electronic products, the market is constantly faced with new opportunities and challenges for growth and expansion. For the sake of clarity, electrical and electronic equipment refers to products that generate, distribute and use electrical energy or electronic products such as audio, video and semiconductors, excluding computers, computer peripherals and telecommunications equipment. Worldwide, the market is estimated to be worth $3454.94 billion in 2022 and is expected to reach $3739.37 billion in 2023, at a compound annual growth rate (CAGR) of 8.2% (Market Research 2023).

Not surprisingly, the amount of used electrical and electronic equipment, or alternatively termed as waste electrical and electronic equipment (e-waste, or WEEE) (McMahon et al. 2021), generated every year is increasing rapidly, becoming one of the fastest growing waste streams (European Commission 2023; Perkins et al. 2014). In order to address this global problem, there is a strong case for developing an inventory of end-of-life electronic products, which could be established through the creation of an environmentally sound regulatory regime for recycling, allowing for the proper control of e-waste (Rautela et al. 2021). Other researchers highlighted global best practices in e-waste management, emphasising the importance of policy implementation, social awareness and technology requirements to achieve a sustainable and circular economy (Murthy and Ramakrishna 2022).

Information System Prototype for E-waste Management

Data model

We selected one of the most popular advertising websites in Poland to collect data on used electrical and electronic equipment offered for sale by both anonymous and non-anonymous users. The method used is a web crawler developed in Python and integrated with the Selenium framework. This crawler runs continuously on a dedicated server. When the data is extracted, the crawler writes it directly to a CSV file. This data is then processed and stored in our non-relational MongoDB database. To date, we have collected approximately 1.1 million data points from online e-waste ads, since August 2023 and is updated daily. In order to extract valuable insights from the ads, a unique data structure has been developed (see Table 1 for details). It should be noted here, that the current version of the framework is designed to be adaptable, allowing for the inclusion of new categories in the future.

Data presentation

A mock-up that visualises the data presentation in the form of a dashboard is shown in Figure 1. The mock-up represents a modern design and user-friendly platform, our goal is to allow users to explore the price trend to make the best decision when shopping. More specifically, the user interface consists of the following 5

Table 1. Electronic Ads Data Model Structure

Field	Type	Description
item_name	String	Type of listed item
title	String	Advertisement title
content	String	Detailed description
location	String	Seller's location
publication_date	String	Ad publication date
collection_date	String	Data extraction timestamp
price	String	Listed price
category	String	Item category
source_link	String	Original ad link
device_condition	String	Condition of the item
user_registration_date	String	Seller's registration date on the platform

features:

1. **Used Device Search Engine:** An integrated search functionality currently limited to locating pre-owned electronic devices by their names.
2. **Data Export Functionality:** Enables users to export detailed price statistics over time specific to a selected device. This feature aids in data analysis and provides insights into market trends and price fluctuations for individual devices.
3. **Dashboard Widgets:** A set of informative widgets displaying essential metrics, including:
   - *Current Price:* The current price as listed in the advertisement for the used device.
   - *Lowest Price:* The lowest recorded price for the used device.
   - *Highest Price:* The highest recorded price for the device.
   - *Price of a New Device:* The retail price of the device when bought brand new.
   - *Price Difference:* The disparity between the current and the highest recorded prices, indicating potential savings.
4. **Price Trend Graph:** A dynamic chart visualizing the temporal evolution of the device's price, enabling users to discern market trends and make informed purchase decisions.
5. **Electronic Listings Table:** A comprehensive table showcasing electronic device advertisements. Upon selecting a device from this table, users are presented with in-depth statistics. The table columns encompass:
   - *Item Name:* The designated name or model of the electronic device.
   - *Category:* The broader classification to which the device belongs.
   - *Date of Announcement:* The date on which the listing was publicized.
   - *Price:* The proposed selling price of the device.
   - *Device Condition:* The operational state of the device.
   - *Location:* The location from where the device is being sold.

In summary, the designed mockup shows database records and a dashboard for a specific example, where the user can search for price trends, check the lowest and highest price, and the difference between the current price and the lowest price. By design, the system is intended to be easy to use, intuitive and helpful for all users.

Discussion

Study Contributions

Our work presents two contributions that concern: a) development of an information system (IS) mockup, specifically designed for the management and pricing of e-waste (Figure 1), and b) extracted data model

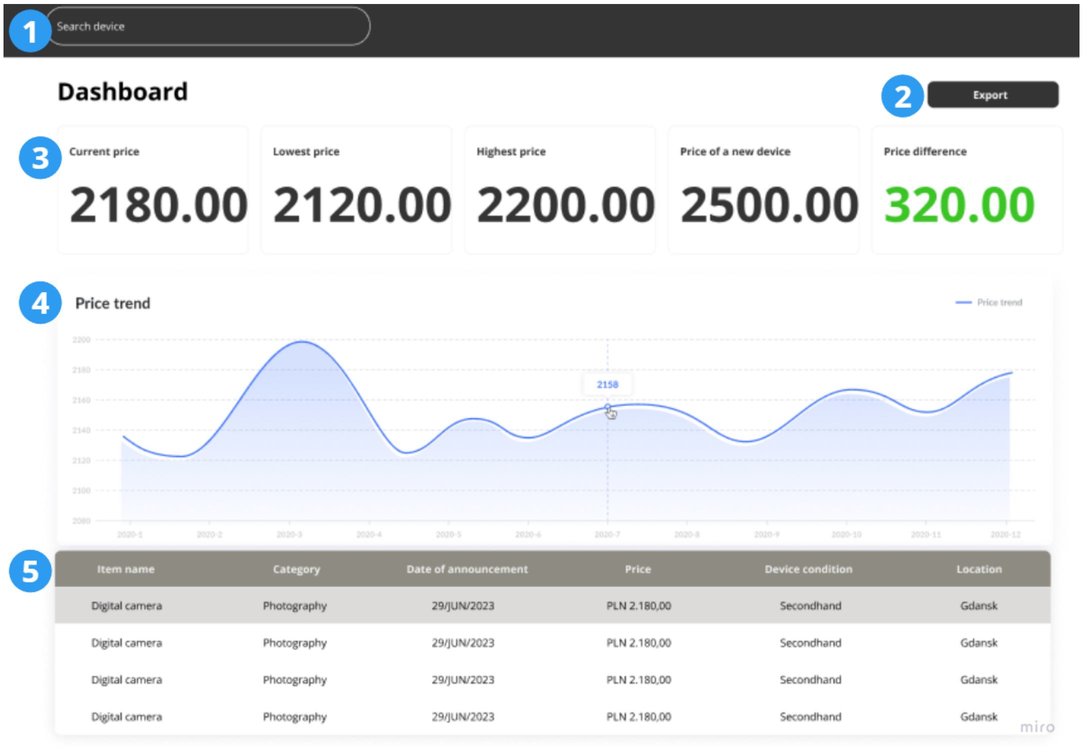

Figure 1. Mock-up of the data presentation dashboard

(Table 1). In this sense, our paper highlights key IS components. By delving into the details of these components, the paper not only provides a blueprint for the technical aspects of the system, but also ensures that the user experience is considered. The dual focus on functionality and user interface is a significant contribution, as it recognizes the importance of user-friendly design in promoting the adoption and effectiveness of the proposed information system.

Study Limitations

Nevertheless, our study has the limitations similar to other related studies. First, the presented solution is only a step towards a tangible solution to bridge the existing research gap and provide a basis for implementing effective policies in e-waste recycling and management. Second, the detailed investigation of the aforementioned components is necessary to validate the practical findings for future development and implementation.

Future Research Agenda

While this paper discusses the current state of research activities to date, future work will focus on two main areas: functional system development and usability testing.

In order to maintain the highest standards and state-of-the-art features of the system, the following functionality is planned:

- **Advertisement Credibility Model**: Create an evaluation system utilizing the advertisement's description and seller's platform tenure to gauge the reliability of the listing.
- **Device Price Alert System**: Enable setting alerts for chosen devices or categories, triggering notifications when prices drop to a specified level.
- **Pricing Models Design and Implementation**: Design a system where users can enter specifics of their intended offer. Utilizing this data, in conjunction with a repository of historical offers, an

estimated market valuation will be presented.

Since usability is considered an important factor in system acceptance by end users (Lin 2013), we see the need for comprehensive usability testing. In short, after the initial release of the system, assigned users will complete a survey to evaluate the beta version of the system. The results will be used to evaluate the quality of the user experience along with any necessary improvements. In other words, this research attempts to measure users' experiences in order to improve existing features and develop new ones that meet their expectations and needs.

Finally, to ensure the effectiveness and success of our system, we have identified the following Key Performance Indicators (KPIs):

- **User Acquisition Rate:** Measures the rate at which new users are registering and using the system.
- **Active Users:** The number of users who actively engage with the system on a daily, weekly, and monthly basis.
- **Search Efficiency:** Measures the average time taken for the system to return search results to the user.
- **Feedback Positivity Rate:** The percentage of positive feedback received from users compared to negative feedback.

Development Road Map

While the current state of our project is at the mockup stage, we have a clear road map for implementing the system. Here's a detailed 7-point breakdown of our planned path:

1. **Backend Development**. Our backend will be developed using Python's FastAPI framework. FastAPI is a modern, fast (high-performance), web framework for building APIs with Python based on standard Python type hints.
2. **Frontend Development**. The frontend of our system will be developed using Angular. Angular is a platform and framework for building client-side applications with HTML, CSS, and JavaScript/ TypeScript. It simplifies the development and testing of such applications by providing a framework for client-side model–view–controller (MVC) and model–view–viewmodel (MVVM) architectures, along with components commonly used in rich internet applications.
3. **Database Integration**. We will integrate our system with a non-relational MongoDB database, as mentioned in the manuscript. MongoDB is a document database, which means it stores data in BSON files, a binary representation of JSON files. This will allow us to store our data in a structured manner, ensuring fast retrieval and efficient storage.
4. **Web Crawler**. Our web crawler, developed in Python and integrated with the Selenium framework, will continuously fetch data from popular advertising websites in Poland. This data will be processed and stored in our MongoDB database, ensuring that our system always has the latest data available for analysis.
5. **Machine Learning Integration**. We plan to integrate machine learning models to provide predictive analytics and insights based on the data collected. This will enable users to get predictive price trends, potential device valuations, and other insights that can be derived from historical and current data. The machine learning models will be developed using Python's popular libraries like TensorFlow and Scikit-learn.
6. **Deployment and Scaling**. Once our system is developed, we plan to deploy it on a cloud platform, ensuring high availability and scalability. This will allow us to handle a large number of users simultaneously, ensuring smooth performance even during peak usage times.
7. **Security Measures**. Given the nature of our system, security is of paramount importance. We will implement standard security measures, including data encryption, secure API endpoints, and regular security audits, to ensure that our users' data is always protected.

Conclusions

In this research, we identified the data model attributes that laid the foundation for the developed prototype of an information system for e-waste management and pricing. These attributes were derived from the combination of reviewing the relevant academic literature, along with processing and extracting online advertisements. These two methods effectively converged in identifying all necessary attributes. Secondly, we presented the first version of the user interface mockup. This visual representation, an essential part of the design process, depicts both information architecture and functional design.

As users involved in the exchange of used goods require design solutions that contribute to efficient exchange operations, instant communication and real-time access, this study informs software development practitioners about potential ways to better address requirements elicitation. In addition, the results can guide researchers and practitioners in developing information systems that are both technically robust and user-centered, serving as a practical tool that decision makers, policy makers, and other stakeholders can use to address the challenges associated with the circular economy and the efficient management of used electrical and electronic equipment.

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