Circularity Principles in Crowdsourced Systems

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***Abstract* – High adoption rates of handheld smart devices, such as smartphones, have motivated the rise of crowdsensing methodologies. The corresponding crowdsourced systems – systems whose constituent infrastructure is provided or augmented by the end-users – have been proven very efficient and scalable systems for collecting data from the crowd. However, successfully and sustainably engaging the crowd introduces costs in the form of incentives. Also, the fragmented landscape of crowdsensing applications aggravates the problem of dark data. In this work we address this problem with the introduction of a reference framework for crowdsourced systems that entails circularity principles. Derived from recent developments in Circular Economy, the circularity principles enable the development of crowdsourced systems that are circular by design, by sharing and re-using already existing resources and data. We exemplify the use of the framework via an example use case.**

***Keywords* – crowdsourced systems, crowdsensing, Circular Economy, circularity**

I. INTRODUCTION

Over the years, several technological advancements have led to the development of advanced methods for developing data collection and curation frameworks. Typical approaches for developing corresponding systems often result in the involvement of specialized equipment that incur significant overheads in terms of cost and efficiency in system resources.

Crowdsourcing and crowdsourced systems represent innovative, open and more efficient approaches of data collection that invoke the general public. According to the International Telecommunication Union (ITU), crowdsourced systems are "*systems that employ crowdsourcing in order to augment their constituent infrastructure and the set of provided services or collected information*" [1]. While crowdsourced systems provide an efficient and scalable method of data collection, the corresponding landscape of crowdsensing applications is highly fragmented; typically, for every new application, a new system is put in place and new data are collected. This aggravates the rising problem of *dark data* [2]*;* data that have been collected but are not used in any process (e.g. analytics). Veritas estimates the global cost of dark data to reach $3.3 trillion USD by 2020 [3]. The case for addressing this problem is compelling.

Towards increasing the efficiency and sustainability of systems, Circular Economy promotes a socio-economic paradigm that provisions the sustainable development of systems and services. Initiatives such as the recently introduced Green Deal action plan in Europe [4] and the ReSOLVE framework by the Ellen McArthur Foundation [5] are considered important steps regarding promoting green choices and utilization of emerging and innovative ICT technologies to replace wasteful processes and protect the natural environment from further damage.

Our contribution. We investigate the intersection of emerging networking paradigms employing crowdsourcing with Circular Economy and introduce a reference framework for incorporating circularity principles in crowdsourced systems. Initially, we set the scene by reviewing the different types of crowdsourcing applications and existing corresponding systems. We review different architectures, the enabling technologies used and the most common incentive mechanisms employed in order to engage the crowd. Then, we elicit relevant circularity principles by analyzing the ReSOLVE framework and the Green Deal Action Plan by the European Commission regarding their stages, their connection to emerging ICT, and methods of implementation. Finally, we present an innovative reference framework for the development of crowdsourced systems entailing the elicited circularity principles and exemplify its use via an example use case.

II. RELATED WORK

In this section, we review the current state of the art with respect to crowdsourced systems. In [6] authors research the development of a crowdsourced framework, supported by Internet of Things (IoT) technologies. The researchers utilize crowdsourcing in order to plan, develop and maintain IoT ecosystems that maintain up-to-date data sourcing and application integration through crowd technologies. The crowd is encouraged to share their sensors' data, contribute to their processing, as well as to the development and testing of validation rules.

In [7] and [8] authors develop a testbed for Smart Buildings, based on IoT technologies while utilizing resources gathered by the crowd located into the facility where the testbed is installed. The testbed comprises a Smart Luminance system that employs participatory crowdsensing using sensors of smartphones in order to augment the sensory capabilities of the system and optimize indoor lighting. A similar approach is followed in [9] where different types of testbeds are implemented, regarding location and conditions, by adopting crowdsensing approaches via smartphones of the crowd. The system performs sensing and actuation tasks while improving data gathering and processing through its end-users, while taking into consideration security and anonymity aspects.

Another example of a crowd-based IoT framework is presented in [10], where the authors attempt to expand the research field of crowd technologies by investigating technical and business perspectives in order to promote the development of the corresponding crowd frameworks and ecosystems. The researchers support the statement with an indicative framework that calculates the amount of emphasis that one of the perspectives mentioned is applied upon a crowd-based IoT system. A generic approach on crowdsensing solutions is presented in [11] by examining state-of-the-art applications and architectures and the incentives utilized to successfully sustain crowd participation. Moreover, the researchers transform vertical architectures into horizontal ones towards the development of a unified framework and ecosystem that is adapted to specific business opportunities.

III. Crowdsourced Systems

A. Applications of Crowdsourced Systems

Crowdsourced systems are conceptually a relatively new type of system, enhancing automation, task completion, data gathering, assistance in the physical world and socio-technical networking. Applications can be categorized and identified according to the concept of their designed model, as well as the targeted end result. Here, we refer to categories of core importance and to those that have already been implemented into actual commissioned systems. Such categories are:

- *Social Systems;* They focus on applications where the user interacts, either with other users or with the application itself, in a social manner. The goal is for the application to assist and facilitate social interactions. Examples of such applications are [12] and [13].
- *Transportation;* Includes systems that facilitate the mobility of pedestrians and drivers or promote and support the use of public means of transport. Indicative examples of such approaches are presented in [14].
- *Infrastructure;* Includes applications that assist in the detection of physical damages by incorporating the crowd into the detection system. Suggested approaches can be seen in [14].
- *Public Safety;* Includes assistive applications in the domains of safety and protection of the user by helping avoid situations that could potentially endanger their wellbeing. Proposed applications have been researched in [15].
- *Healthcare;* Includes assistive applications targeting general fitness, wellbeing and health of the end users. Examples of indicative applications are refered in [15] and [16].
- *Environment;* Includes applications that address both the ecological aspects of their design and the ambient environment of the end user. Proposed applications have been researched in [17] and [18].
- *Energy Management;* A recently introduced category, representing crowd approaches related to energy balancing and energy sharing among members of the crowd. Corresponding applications are presented in [19] and [20].

B. Architectures of Crowdsourced Systems

1) Reference Architecture

The majority of models for crowdsourced systems follow a specific archetype of crowdsourcing designs that is used as the foundation of the system. This archetype can be categorized into four layers [21];

- *Application Layer;* It is dedicated to the organization of the task that is implemented into the concept of the crowdsourcing system, as well as managing the interaction between the crowd and the task itself.
- *Data Layer;* It consists of all the available procedures, depending on the application's framework, which are responsible for data gathering, processing, management and maintenance once they are collected from the crowd.
- *Communication Layer;* It is responsible for the different methodologies and technologies which are implemented into the system for the communication and data exchange between the devices and the task's database.
- *Sensing Layer;* It is dedicated on the selection and management of the sensors required, to fulfill the application's modelled task by collecting the data in an efficient manner.

2) Architecture Designs

In 2015, the differences between *vertical* and *horizontal* architectures were thoroughly investigated and described as potential solutions for crowdsensing applications [11]. Authors concluded that the majority of the applications would follow a vertical type of architecture, rather than a horizontal one.

Vertical architectures are focused on specific or trademarked applications. In other words, vertical architectures are strictly operated under one task provider, while being completed for one specific application which is registered on one device. The applications and services of the system's providers are essentially focused on intercommunication of the devices. Horizontal architectures are more flexible and multitasking friendly. They are capable of combining different types of tasks, operations and processing their data simultaneously. All data are stored into a database or cloud where analytics and information extraction take place.

In [11] authors investigate the differences between opportunistic and participatory architectures, regarding their strengths and weaknesses, as well as the uses cases where each one could be applied on.

TABLE I. Incentive Mechanisms

Incentive Mechanism	Type	Achievement
Monetary	Extrinsic	Monetary reward, depending on number and type of sensors utilizided
Entertainmet	Intrinsic	Gamification of task and location-based mobile games
Service-based	Extrinsic	Collaboration among users through task requesting and submission, Survey Completion
Ethical responsibility	Intrinsic	Willingness of user to participate in task. Emotional reward of assisting other users. Charity type tasks, through philantrophic monetary donations

Opportunistic architectures are specifically designed to allow a user to collect data from their personal devices while they carry on with their daily tasks with the data being automatically sent to the system's main database. Participatory architectures require the task user to actively interact with the application and the system in order to provide the required data. In this case, the system needs to incentivize the users in order for them to allow access to their personal devices.

3) Other Aspects of Crowdsourced Systems

Incentive Mechanisms are essential in order to motivate a user to participate in a task, since users consume resources in order to contribute to crowdsourcing applications. The most common categories of incentive mechanisms include monetary incentives, entertainment, service-based incentives and incentives pertaining to ethical responsibility. Table I summarizes the different categories, their type and ways of delivery.

In [13] authors investigate security and privacy aspects of mobile crowdsourcing systems[22]. Findings support that potential threats are related to geolocation and biometric information, financial and medical records, as well as submitting personal data for a task completion. Such threats can be used in order to predict or detect the user's identity.

Another research in [14] investigated security requirements that should be considered in a crowdsourced system[23]. The authors concluded that the corresponding requirements should be focused on confidentiality and integrity to ensure anonymity, authenticity for masked approach protection, privacy regarding identity and submitted data, access control for providing the choice of the time, location and type of data submitted by the user.

Suggested defense mechanisms from [9] and [18] support the implementation of credentials for identity verification, IP masquerading and anti-spoofing for anonymity, as well as TCP/IP and TLS/SSL for data and device protection. Moreover, education and raising the awareness of the crowd on security and privacy threats is essential for safe participation into tasks.

IV. DATA-DRIVEN CIRCULAR ECONOMY

A. Introduction and Definition

Data-driven Circular Economy can improve the production process by processing certain products under different stages to increase lifespan and improve quality, tracking use cycle for proper decision making through data of environment conditions, location and use frequency and improving economic conditions by sharing assets through the concept of circular economy[24].

The Ellen McArthur foundation has publicly announced its interest on circular economy approaches with the publication of their toolkit for policymakers on circular economy [5], which consisted of six parts:

- <u>Regenerate:</u> Dedicated on shifting to renewable energy and materials, with the goal of restoring the health of ecosystems.
- <u>Share:</u> Focused on encouraging sharing and reusing assets, while modeling the future in order to enable upgradeability options and improvements.
- <u>Optimize:</u> Designs and models on improving the efficiency and performance of produced products, while incorporating state-of-the-art technologies of automation, big data and sensing.
- <u>Loop:</u> Reusing can lead to remanufacturing products and components, recycling materials rather than disposing them, and extracting biochemicals from organic waste.
- <u>Virtualize:</u> Based on direct and indirect dematerialization of commissions.
- <u>Exchange:</u> Focused on replacing old appliances into new ones. The Foundation uses the example of new technologies such as 3D printing and choosing new products or services, which are friendly for the ecosystem.

The Green Deal is another initiative applied by the European Commission, in order to provide a fully detailed and optimized agenda, that can assist Europe into its own transformation into utilizing a cleaner and more economic model through actors, consumers, citizens and civil society organizations [2]. The framework designed to be adopted by the European countries is as follows:

- <u>Designing sustainable products:</u> Features of this initiative refer to upgrading durability, reusability and reparability of products, while minimizing harmful chemical and improving efficiency and robustness. Implementation of new technologies into the products' blueprints are also attempted, such as digital tracking and recording, passports and tagging.
- <u>Empowering consumers and public buyers:</u> Dedicated on the support of clients, in order to provide economic opportunities, by ensuring data gathering on lifespan, availability of repair services, replaceable components and repair manuals.
- <u>Circularity in production processes:</u> Focused on industrial implementation by incorporating available options of industrial circular economy upon the production chains and development of an industry-based reporting and certification system. Part of the technology implementation is further motivation of utilizing green-technologies as part of the industry.

B. Underpinning Technologies

Internet of Things (IoT) features, such as smart sensing, can be utilized in order to collect data that are distributed across connected stakeholders while evaluating consequences of actions for the lifespan of produced products. Followed by data analysis due to the multiple sources being able to connect into an IoT platform, and its potential of creating an industrial co-operation for circular economy.

Artificial Intelligence (AI) provides automatic and remote monitoring during manufacturing processes, as well as tracking a product's lifespan, it supports large scale of data analysis and provides faster and more efficient feedbacks, while it can be trained to perform certain learning cycles in order to form effective economic models.

Big Data Analysis (BDA) is responsible for the capability of massive analysis in terms of quantity, quality and variety, while being utilized in production and supply chains. Moreover, BDA help gain insight for process integration, management and sharing, that lead to efficient and robust decision making on manufacturing and industrial actions.

Blockchain in combination with Edge Computing are utilized in order to provide effective storage location of blockchain data and for utilized 5G communication protocols

TABLE II *ICT AND APPLICATIONS ON CIRCULAR ECONOMY*

Underpinning Technologies	**Applications**
Internet of Things	Smart Sensing for data collection Data analysis due to multifunctionality Product passport
Artificial Intelligence	Part of product design Automatic and remote monitoring Tracking lifespan of product Data analysis in large scale Feedback and prototyping Capable of being trained for certain loops
Big Data	Massive analysis Being utilized in production and supply chains Green economy approaches Insight generation
Blockchain & Edge Computing	Storage of blockchain data Able to support 5G Encrypted timestamps and digital handshake

capable of transferring and sharing money or data that are followed by encrypted timestamps and digital handshake to ensure security among clients. Table II presents an overview of the underpinning technologies and their corresponding applications.

TABLE III The RESOLVE FRAMEWORK AND ITS RELATION TO CROWDSOURCED SYSTEMS

ReSOLVE Stages	**Crowdsourcing - Crowdsourced**
Regenerate	Use cases of smart appliances while gathering data from the crowd for ecological purposes
Share	Availability of service among users Data and resources sharing
Optimize	Sharing processing and computational power Utilization of personal sensing devices to report ecological issues
Loop	Reuse of data for updating and developing existing platforms and tasks
Virtualize	Utilizing personal sensing devices rather than specilized equipment
Exchange	Enabling crowd to report economic and green choices

V. A FRAMEWORK FOR CIRCULAR CROWDSOURCED SYSTEMS

We introduce a reference framework for the design and development of crowdsourced systems entailing circularity principles. The ReSOLVE framework by Ellen McArthur Foundation and the Green Deal Action Plan by the European Commission act as a foundational base regarding the fundamental principles that should be implemented upon a circular crowdsourced system.

As a first step in designing the proposed framework, we conduct a critical comparison between the stages of the ReSOLVE framework and crowdsourcing principles in order to investigate how crowdsourcing is linked with each stage of ReSOLVE. The results of our comparison are presented in TABLE III.

Following we conducted a similar comparison with respect to the Green Deal Action Plan. As a result, a unified table is derived where each stage of the ReSOLVE framework is liaised to the three steps of the Green Deal Action Plan, concluded into the potential results of crowdsourced adaptations and approaches. TABLE IV presents the corresponding outcomes.

A. The Proposed Framework

Taking into consideration the results of the comparisons, we proceed by designing a reference framework for circular crowdsourced systems (Fig. 1).

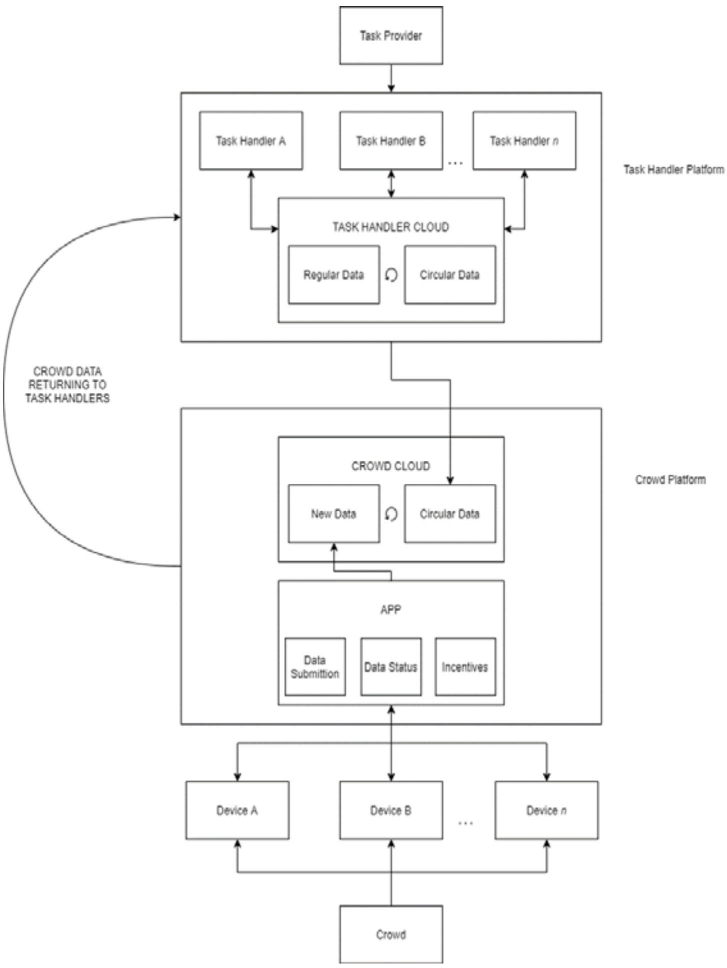

Fig. 1. Proposed circular crowdsourced system framework

The framework consists of the following:

Task Provider: The task provider is the direct beneficiary that issues the corresponding task to potential task handlers, describing the purpose, requirements, specifications, data required as well as the role of the crowd and the incentive mechanisms to be used, in order to engage the crowd.

a) *Task Handler Platform:* The platform consists of the task handlers and a cloud where the required data are stored. To be more specific

- *Task Handler:* They are selected individuals or organizations by the task provider, who officially agree to partake and cooperate in the task by managing and processing data, while sharing them with the crowd for its completion.
- *Cloud:* It is the main functional part of the Task Handler Platform. The cloud is designed in order to separate the data into two groups, the regular data and the circular data. As regular data we define the data that can be characterized as primary or as additional data that have been already registered into the cloud. As circular data we define the type of data that have returned from the crowd to the task handlers and went through any of the circular processes of reuse, remanufacturing or recycling. Both regular and circular data can be read and edited by all the task handlers, in order to properly manage, process and optimize the data, as well as their own functionality. The data are also in a constant loop of updating in order to be categorized in the proper data type group, once they are submitted by the task handlers. Moreover, the data stored into the cloud are sent into the third part of the framework, which is the Crowd Platform.

b) *Crowd Platform:* It consists of the Crowd Cloud, where the data sent from the Task Handler Platform are stored and the application that enables the users of the crowd to interact with the data provided.

- *Crowd Cloud:* It is the first component of the third part of the framework and functions as the basis of the Crowd Platform and receives the data that were stored in the Task Handler Platform. Crowd Cloud is designed in order to categorize the data into two types; new data and circular data. We define as “new data” the type of data that are submitted exclusively from the crowd, through the submission component of the crowdsourcing application. We define as “circular data” the type of data that the crowd has fetched from the Task Handler Cloud, and there are either predetermined data and information or data that have undergone reuse, recycling or remanufacturing (as per the

TABLE IV. CONNECTION OF RESOLVE, GREEN DEAL AND CROWDSOURCED SYSTEMS

	Regenerate	Share	Optimize	Loop	Virtualize	Exchange	Results via crowd
Designing sustainable products	X	X	X		X		Creating energy sufficient and ecologically friendly smart crowdsourced applications, while promoting reuse of valid data and sharing of resources among task users.
							Capability of utilizing new technologies on crowdsourced systems and personal sensing components of the individual's device, rather than energy and cost consuming equipment.
Empowering consumers and public buyers		X		X		X	Enabling data sharing and reusing between clients and enterpreneurs on improving economic friendly products through crowdsourced use cases, in order to update or uprgrade existing systems and platforms
							Promoting healthier and ecological friendly solutions between enterpreneurs and clients
Circularity in production processes	X	X	X	X	X	X	Creation of crowdsourced systems that can be adapted for industrial use and provide ecological alternatative of industrial processes. It is achieved through implementation of new technologies, reuse of data on production and supply chains and data sharing between the industry's departments. Resulting in energy and cost efficiency, as well as adaptation of circularity on newly designed products.

- ReSOLVE framework). Moreover, Crowd Cloud operates in a
- constant loop in order to categorize the corresponding data into the proper categories. Last function of the Crowd Cloud is to return only the required data back to the Task Handlers, while preserving security and privacy technologies for the protection of the Crowd.
- *Application:* It is the second component of the Crowd Platform and functions as the interactive mechanism between the crowd and the Crowd Cloud. The application performs three operations in order to be fully interactive for the user: Data Submission, Data Status and Incentives. Data Submission is the mechanism or mode that the user interacts with in order to submit new data into the Crowd Cloud, into the New Data group. Data Status operates as the descriptive mechanism regarding the verified conclusive information of the data, when the user interacts with the application. Incentives are the mechanisms designed within the application in order to entertain the crowd, promote participation and encourage further use of the crowd platform for the corresponding purpose. Finally, the application can be operated through the personal device of each user, either portable or stationary.

B. An Example Use Case

For better understanding the functionality of the framework, we discuss its application on a use case under the Infrastructure category.

At a national level, governments and their corresponding ministries of infrastructure can be identified as Task Providers, by implementing an initiative of reporting and monitoring construction damages, electricity outages or water supply issues. They are capable of identifying and approaching suitable Task Handlers that can take responsibility of the functionality of such projects and to be fully responsible for describing the requirements of the project to the Task Handlers, as well as the data required regarding new construction schedules and reported damages, or issues pertaining the privacy of the users that submit such data into the corresponding platform. Potential Task Handlers for this use case are construction companies, organizations powered by the public sector and local municipalities.

The Task Handler platform consists of all participating construction companies, organizations of the public sector and the private sector and have full access into the common cloud provided. Data on the cloud is divided into the following:

- New infrastructure damages that are about to be scheduled for repairing and be submitted by the organizations themselves, as primary source of data.
- Scheduled or reported damages and issues that were submitted by either the Task Handlers or the crowd, through the whole process of the application.

The cloud is fully open accessed, which means that Task Handlers are able to read and edit data that are stored on the cloud. A benefit of such a system is the potential of optimization regarding construction scheduling of each damage case, as well as time and cost efficiency. In other words, each service can schedule the construction sites accordingly, while calculating dates and incorporating locations, in order to optimize each schedule according to type of damage.

The Crowd Platform consists of the Crowd Cloud and the Application that is available for the general public. The Crowd Cloud is categorized into the following:

- The reported damages that the crowd submitted through the corresponding mode of the application and it's exclusively designed for the specific purpose.
- The fetched planned or scheduled construction damages that are about to be fixed and are stored into the second group of data into the cloud, in order to be utilized into the Constructions Status and proper categorizing of further imported data.

The Crowd Cloud is connected to the Application available for the crowd and is specifically designed with three modes that enables the user to interact and participate to the project:

- *Damage Report:* They are submitted in the form of photos capturing inflicted damage when the user is on sight or a video capturing user's vocal description of the damage. The attached files can be accompanied with text description of the case and the corresponding details regarding location or type of damage. An alternative solution regarding location data could the user consenting to provide their GPS location data of their personal device.
- *Constructions Status:* It depicts live construction reports or cases with scheduled repairs, in a real-time map with an indicative symbol on each location in order to be easily understandable and recognized by the crowd. Alternative solution is a fully detailed list regarding location and type of damage, in case there is trouble of loading the map into the user's device.
- *Incentives:* The Municipality and Task Handlers can arrange a set of incentive mechanisms that can promote participation and motivate for further use of the application. Such examples are personal appreciation messages, a reward system and credit collection leading to discounts for each submission, promoting participation that could lead, for example, to charity events.

Data submitted can be either captured and submitted on spot through the individual's mobile device, or simply captured and uploaded once available, through the corresponding desktop platform using a computer. Moreover, once submitted data undergo an updating loop, in order to be compared with the scheduled constructions that were fetched from Task Handler's cloud and provide the relative information required.

The application concludes with the return of the submitted damage reports back to the task handlers, in order to be analyzed and categorized properly to the suited categories, and promote circularity once they return to the depiction status of the application. The returned data undergo an updating loop on the Task Handler's platform, similarly with the Crowd Platform, in order to be linked with potential existing data on the New Constructions, without the need of being utilized, or being placed into the reported and planned constructions.

VI. Conclusion

In this paper we discuss the need for developing efficient systems in terms of re-utilizing already existing resources, as highlighted by the problem of dark data. We proposed a reference framework for crowdsourced systems entailing circularity principles, aa these are defined in Circular

Economy. The proposed framework is not limited into a specific implementation with respect to the application area, but can be applied on various use cases, thus leading in the development of circular crowdsourced applications.

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