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Iot-Sensor-Equipped Food Waste Bio-Composter to Households and to Advance Egovernment in Municipality Authorities' Waste Management Practices

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Abstract

Background: Finnish policymakers issued a new community waste law in 2022, that aims to increase household food waste recycling. The municipalities have launched the implementation of the waste law and are responsible for supervising the development of this new project.

Problem: The implementation and supervision of the waste law increases authorities' workload and also public costs. Public servants manage the households' compost register and carry out compost audits on-site.

Challenge: The challenge is to put in place the new waste management law at the lowest public cost.

Purpose: The research addresses the validation of a pioneering IT solution that supports and advances households' bio composting and aims to ease waste management authorities' workload by fostering eGovernment.

Methods: The intervention consists in delivering the IoT-sensor-equipped bio-composter and associated applications. The research adopts a mission-oriented approach, and establishes a place-based, multi-actor, participatory, and open innovation testbed at Living Lab. It leverages the Lean Startup process and SWOT analysis. The research method complies with the principles of Responsible Research and Innovation.

Conclusions: The IoT-sensor-equipped bio-composter is a feasible solution. Municipality waste management authorities do not regard/consider the IoT-sensor-equipped solution as beneficial from their perspective. The eGovernment strategy is not a driver in this case since bio-composter mapping and monitoring could be a future tool for real estate maintenance companies.

Keywords

Legislation, municipality, food waste, recycling, bio-composter, Living Lab, Internet of Things, eGovernment, city region, food systems.

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Introduction

In 2020, around 127 kilograms (kg) of food per inhabitant were wasted in the European Union (EU). Households generated 55% of food waste, accounting for 70 kg per inhabitant (EUROSTAT, 2022; EUROSTATa, 2023; EUROSTATb, 2023).

United Nations Sustainable Development Goal (SDG) number 12 is Responsible Consumption and Production. SDG target number 12.3 proposes to halve per capita global food waste at the retail and consumer levels by 2030 (FAOa, 2023; FAOb, 2023).

The European Commission is in the process of proposing legally binding targets to reduce food waste across the EU. The EU Waste Framework Directive 2023 will assess the feasibility of setting food waste reduction targets to implement the Union's commitments under the UN Sustainable Development Goals and the Farm to Fork

Strategy and limit the food supply chain's impact on the environment and climate. European Commission (EC) will inform the targets by the end of 2023 (ECa, 2023; ECc, 2023; ECd, 2023; ECe, 2023; ECf, 2023).

The waste reduction hierarchy includes prevention, preparing for reuse, recycling, recovery, and disposal. Preventing waste is the preferred option, and sending waste to landfill should be the last resort (EC, 2020).

This research addresses the recycling of Finnish households' food waste into new compost soil by using bio composting. Finnish households should improve their community waste collection and recycling, which, in 2020, covered merely 42 percent. EU countries' target for community waste recycling is 55 percent by 2025 and 65 percent by 2027. Finland's community waste keeps on increasing and the recycling rate is too low at this pace. Reaching the EU target looks far away. Under the circumstances, and as specified before, households must improve food waste separation from mixed waste to enable food waste recycling into new products (LUKE, 2021; Circwaste, 2022; Ympäristö, 2018; Hina et.al., 2022; Dhir et.al., 2020).

In 2021, the Finnish government updated the waste management law, with the aim of improving households' food waste recycling. It came into force this year (2023). Communities with more than 10,000 inhabitants are legally required to organize food waste collection (Finnish Ministry of Environment, 2021).

The new law increases inhabitants' general awareness of food waste value, and it emphasizes food waste separation from other household waste and recycling of food waste. The aim is to increase the quantity and quality of collected food waste to promote recycling. The industrial processes which produce biogas, compost soil, and biochar make use of collected food waste.

The new waste law also promotes households' small-scale bio-composting on their own premises. Composting reduces food waste transportation from households to centralized food waste processing units, which, in the long term, reduces household food waste management costs. Food waste composting outcome, which is compost soil, is a valuable resource for gardeners. Compost soil improves garden soil quality which, in turn, enhances growth and yield. Households' bio composting and gardening go very often hand-in-hand.

The new waste law requires that local waste management authorities keep a composter register on food waste. This register includes data on households that manage a bio-composter. Thus, the composter register assists authorities in watching and guiding the households' composting practices. Authorities can make compost audits of households, gather data on the households' quantity of food waste and its recycling, and record the data in the statutory composting register. Finally, the authorities use food waste data to calculate Finland's food waste recycling rate.

The implementation of the new waste management law inevitably increases e public costs. The public bodies and operators put effort into upkeeping the composter register, auditing households on site, and collecting data on waste food quantity. The waste management authorities and operators in the city region work with tax funds. They invoice the costs from the households via community waste billing. At the end of the day, the households will pay the increased community waste management costs. The payment takes place either through increased taxes or community waste bills.

The **problem** is that the implementation and supervision of the new waste law increase the authorities' work and public costs. Public servants manage the compost register, compost audits, and data collection. The **challenge** is to put in place the new waste management law with the lowest possible public service costs.

This means that the manner to build the composter register needs to be as automatic as possible. The amount of human work should be reduced to the minimum, which involves carrying out auditing sessions without physically going to households. The bio-composter auditors' work must be done remotely. This also means that the data collection on households' food waste recycling volume should be reconsidered, in terms of reducing manual workload in data collection to the minimum possible hours.

European Commission fosters transition to effective digital public services and eGovernment, which develops smart tools, rethinking organisations and processes, and changing behaviour so that public services are delivered more efficiently to people (EC eGovernment, 2023).

The key intervention in the research is an IT architecture and application. The IT solution, which is associated with food waste bio composter, is pioneering. The IoT sensors and LoRaWan technology have not before been introduced

and piloted in the context of households‘ food waste bio composting (Digita, 2023).

In this research, three households in Finland test an IoT-sensor-equipped bio composter, which leverages LoRaWan technology for data transfer.

Further, the municipality waste management authorities and other biowaste collection and recycling-related stakeholders were invited to participate in the research action. Their role was to assess and give feedback on IoT-sensor-equipped bio composter taking into account the new waste management law requirements and consequent new tasks for municipalities.

The research questions are as follows:

RQ1: What is IoT-sensor-equipped bio-composter feasibility?

RQ2: What kind of weaknesses, strengths, opportunities, and threats do the involved households, the product owner (Biolan Oy), public waste management authorities, and other stakeholders envision in the IoT-sensor-equipped bio-composter uptake and execution?

Materials and methods

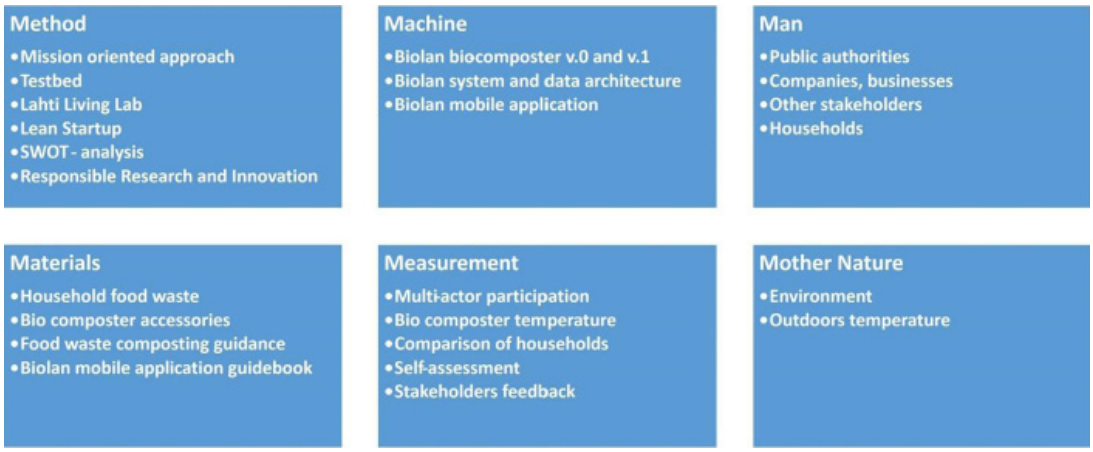
The research framework includes six elements, namely: method, machine, man, material, measurement, and mother nature. Figure 1 outlines the main sub-variables for each element, and every element is analysed in this chapter.

Method

The purpose of this applied science research is to test and assess the pioneering IT solution whose aim is to ease public waste management authorities' bio-composting-related tasks in households and foster eGovernment. The research applies a wide range of approaches and methods that are mission-oriented, place-based, multi-actor, participatory, open innovation, structured, analytical, and ethical.

Mission-oriented approach: The research aim is to contribute to the European Commission’s vision and objectives, namely Food 2030 policy via innovation actions that are conducted in the Horizon2020 project Cities2030 (Cities2030, 2020). The main missions of the Food 2030 policy are as follows: 1) Nutrition for sustainable and healthy diets. 2) Food systems supporting a healthy planet. 3) Circularity and resource efficiency. 4) Innovation and empowering communities. This research contributes to the third and fourth missions (ECb, 2023). The research also contributes to achieving the specific objective of the Cities2030 project i.e. "Enhance circularity and local food belts". The research responds to the challenge of promoting the circulation of nutrients contained in urban household food waste from the table back to the soil.

Testbeds: Three households tested the solution on their own premises in Eura, Rauma, and Lahti. Further, one of the testbeds invited the municipality waste management authorities to join in and assess, respectively, provide feedback on the solution. This extended testbed was established in the city of Lahti. Lahti is a city of 120,000 inhabitants and about 31,000 households. Lahti is located in southern Finland, in the county of Päijät-Häme. The local community waste management operator is Salpakierto Oy, that is responsible for implementingt the waste management law. Lahti municipality waste management authorities control



Source: Smart & Lean Hub Oy, Tuula Löytty

Figure 1: Research framework

and guide Salpakierto's processes and performance. Salpakierto food waste management experts have estimated the number of households' composters and, accordingly, 10-15% of Lahti households own a bio-composter. This means that Salpakierto Oy will register and audit at least 3,100 households in the city of Lahti (Salpakierto, 2021; Salpakierto, 2023).

Lahti Living Lab: Cities2030 project fosters urban food system transformation by carrying out innovation actions e.g., experiments and capacity-building actions in a local setting. The operational multi-actor platforms for innovation actions are place-based Living Labs. Living Labs' aim is to generate innovations and empower multi-stakeholder communities in an open innovation environment. Lahti Living Lab from Finland is part of the Cities2030 labs, and contributes to achieving the Lahti Vision 2030, namely "Lahti is a sustainable and carbon neutral city region". Lahti Living Lab is a multi-actor, participatory, and open innovation environment and testbed for IoT-sensor-equipped bio-composter (Lahti Living Lab, 2023; Bogers et.al, 2017; Hirvikoski et.al, 2020).

Lean Startup: The research procedure applies the Lean Startup methodology, which is based on the following concepts: Ideate - Build - Monitor - Learn. The Ideate phase is dedicated to planning the research procedure. The building phase is twofold: a) food waste bio composter preparation in the test site and b) ICT architecture, sensor-, IoT- and data collection and architecture solutions at Biolan Oy. The monitoring takes place in three steps: Biolan Oy's self-assessment, households' self-assessment, and waste management authorities and bio waste stakeholders' consultative assessment and feedback. The last phase, i.e. Learning purpose, is to answer to following business and proposed questions: "Does this product serve as a solution to the set challenge?" "Should this product be built?" and "Can we build a sustainable business around this set of products and services?" (Lean Startup, 2023).

SWOT-analysis: SWOT analysis is a brainstorming tool that facilitates participants' communication and assessment on the topic regarding current strengths and weaknesses and future opportunities and threats as well. The waste management authorities and stakeholders' consultative assessment and feedback are included in the SWOT analysis (Benzaghta et al., 2021).

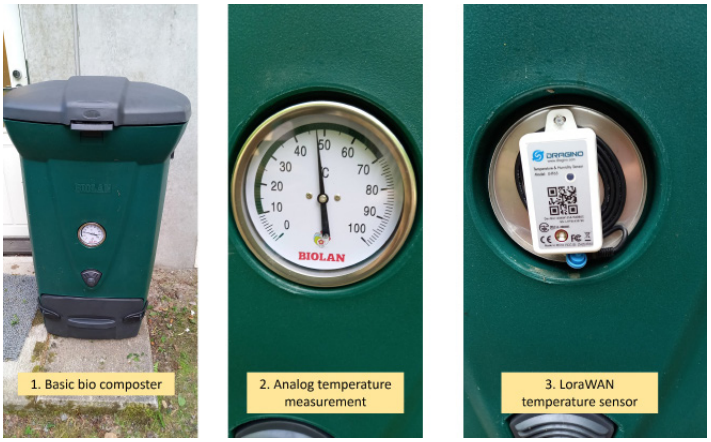
Responsible Research and Innovation (RRI): The research is conducted as a part of Cities2030 project which is funded by EC's Horizon 2020 program. Cities2030 delivers a project RRI framework to contribute to the EC's vision of an inclusive, innovative, and reflective society. The basic RRI toolkit comprises 6 themes: Ethics, Gender Equality, Governance, Open Access, Public Engagement, and Science Education (RRI, 2023). The purpose of the Cities2030 project is to ideate, co-create, implement, and pilot RRI tools and concepts under research and innovation actions, which are meant to structure a Cities2030 RRI framework for the responsible co-creation, pilot, and deployment of innovations.

Machine

The Machine - element refers to facilities, systems, tools, and pieces of equipment employed for the research.

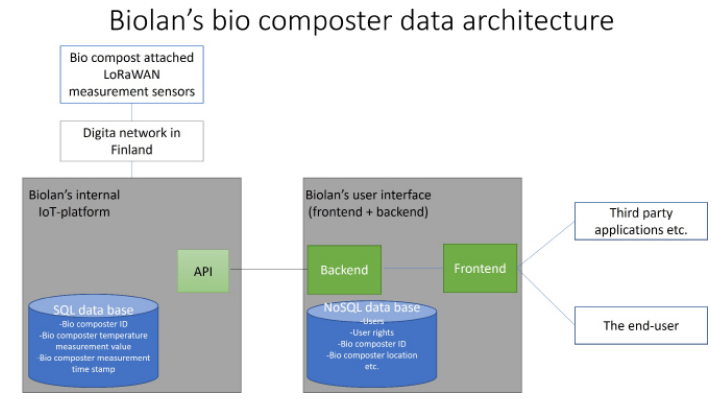
Biolan bio composter: Biolan Oy is a Finnish family business specialising in developing, manufacturing, and marketing products that help reduce the environmental impact of daily human activities (Biolan, 2023). The basic bio composter, version 0, which is addressed particularly to households is a Biolan Quick Composter 220eco. It is equipped with an analogue temperature measurement (see Figure 2). Biolan Oy developed the first version of the digital sensor-equipped bio-composter in 2018-2019. The idea was to substitute the analogue temperature gauge with a digital sensor to enable continuous temperature monitoring in the bio-composter, and to connect the bio-composter to the internet. It was a pilot of an Internet of Things (IoT) solution. At that time, data transfer become a barrier and thus Biolan Oy left the idea aside for a couple of years. In 2022, Biolan Oy picked up on the old concept and upgraded it to exploit LoRaWAN technology by using DRAGINO's LHT65 LoRaWAN temperature sensor (see Figure 2). One IoT sensor costs about 50 EUR. The LoRaWAN technology has become one of the key enabling technologies for the development of Internet of Things architectures. It has been very popular and useful in Smart City applications, including public waste management (Biolan, 2023; DRAGINO, 2023; Baldo et.al., 2021; Cruz et.al., 2021).

The first version of Biolan's bio composter is pioneering. The IoT sensors and LoRaWAN technology have not been introduced and piloted before in the context of households' food waste bio composting.



Source: Smart & Lean Hub Oy, Tuula Löytty

Figure 2: 1. Basic bio composter; 2. Analogue temperature measurement; 3. LoRaWAN temperature sensor.

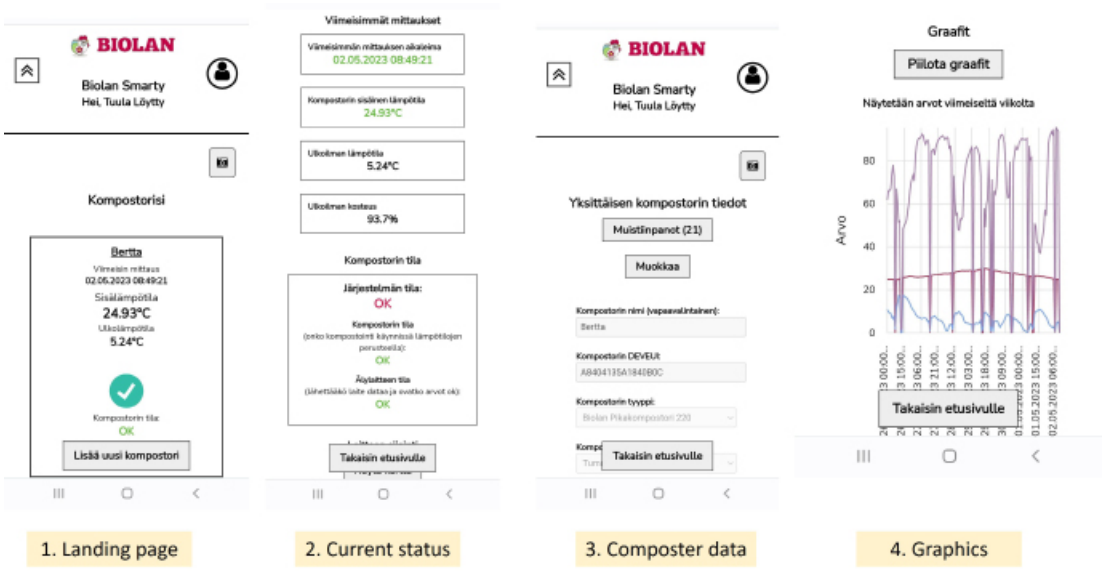


Source: Biolan Oy, Sami Rantamäki

Figure 3: Biolan's system and data architecture schema.

Biolan system and data architecture: Data collection was done utilising sensors connected to composts. Sensors send data every 15 minutes to Biolan SQL-database (System Query Language) through the Internet (Figure 3). In SQL-database, the data coming from the composter IoT-sensors is made into tables in SQL-database. This means that the sensor data is normalised into constructional data which can be easily used in reporting or other applications. Data from sensors is send first to SQL-database instead of directly sending it to programs that utilise the data. This is done because it is easier to control the users of the data, it's easier to share the data to applications which utilise the data in their work and apply additional layer of cyber security. Utilising SQL-database between the IoT-sensor and the applications crates a master database and guarantees that different applications which utilise IoT-sensor are all using the same data from the master database.

Table columns are visualized in Figure 4. After data normalization, data is moved through API (Application Programming Interface) into another database. This is done to prevent end-users and third-party applications from accessing the master database. From NoSQL database composter data is then spread to end-users and into third-party applications, such as Power BI (Figures 6 and 7).



Source: Biolan Oy, Bioapps-application, Sami Rantamäki

Figure 4: Screenshot of Biolan's mobile application.

Man

The Man-element refers to all operative and participating people who are involved and contribute to the delivery of a process and accompanied research. The people represent policymakers, public authorities, businesses, education, science, and households. The term "Man" does not refer to gender, quite the opposite, the gender-balanced research is one of the aims. The research complies with the multi-actor approach in human participation (EIP-Agri, 2017), and establishes a multi-actor stakeholder community to facilitate knowledge exchange and transfer, capacity building and innovation actions, as well as networking among bio- and food waste stakeholders.

Public authorities: The extended solution testbed was established in the city of Lahti, under the wings of Lahti Living Lab. The waste management authorities of the city of Lahti are responsible for implementing and monitoring the new waste law in the city. Authorities establish the compost record, audit households composting practices, and collect data for European Commission about food waste recycling in the region. The aim of the study is to facilitate and easy waste management authorities work with a new approach. Lahti's waste management authorities represent and give a voice to all regional waste management authorities and operators, although from a scientific perspective, their feedback and insight into the solution are not representative. In 2022, 31 regional waste management authorities and operators were mapped in Finland (Karlsson-b, 2022). They are responsible actors for community waste management in all 220 municipalities of Finland.

Companies and businesses: Biolan Oy is a Finnish family-owned SME company whose main products are bio composters, associated goods, and consumables. Biolan Oy owns the intellectual property rights of the IoT sensor-equipped bio composter. Their interest is to extend their market share via new innovative services (Biolan, 2023).

Other stakeholders: Households' biowaste management in Finland interests a wide group of stakeholders, namely actors that are on bio-composting goods and consumables, guidance, logistics, law, regulation, and EU communication. There are also some associations that work for the inhabitants' benefit giving advice and support. And there is a large group of institutions, organizations, associations, entities, and projects that provide services on education, advisory, research, development, innovations, and data.

Households: This study engaged three households willing to test IoT-sensor-equipped bio-composters. The households are located in Lahti, Eura, and Rauma. Eura and Rauma bio composters are internal to Biolan Oy, meaning that the actors are working for Biolan Oy. The household in Lahti is the first external user of Biolan Oy's solution.

Figure 5 shows the mapping of the place of households that took part in the research. The localisation and visualization take place based on Biolan's mobile application registration data.

Materials

Household food waste: The household's normal food waste is the raw material for bio composter process e.g., fruit and vegetable peels, meat and fish waste, etc. food residues, coffee and tea reindeer with filter bags, old flower soil and plant waste, soft and moist papers, crushed eggshells, natural fibers in small pieces.

Bio composter accessories: To maintain and speed up the composting process ongoing, it's possible to add now and then accessories such as composting accelerator and bulking material.

Food waste composting guidance: Although composting is not difficult, it's beneficial for newcomers to familiarize themselves with the procedures of bio-composting. The Internet provides a lot of information on such practices. One reliable source is the bio-composter producers' web page (Biolan, 2023).

Biolan's mobile application guidebook: Biolan delivered a guidebook for the users of the new mobile application. It provides detailed guidance on how households can independently register themselves as a user of the solution and how to further use the mobile application.

Measurement

This chapter addresses the issues of research monitoring and measurement systems.

Multi-actor participation: The goal was to build a multi-actor environment to test and assess the IoT-sensor-equipped bio-composter. To that end, stakeholder reach-out and engagement measures were documented and measured: how many stakeholder members were contacted, what was the typification of the stakeholder, and what was the gender of the stakeholder member. Only one person in this study was responsible for stakeholder engagement and management, and thus the measurement system is considered reliable and traceable.

Bio-composter temperature: As already explained in the chapter Machine, the IoT-sensor equipped bio-composter enables remote monitoring of the bio-composter inside temperature. The collected data is visualised in the mobile application and also in the Power Bi application. The mobile application shows a short time frame of about 12 days. The Power Bi application shows a long-time trend starting from the beginning of August 2022 (Figure 6) (Karlsson-a, 2022).

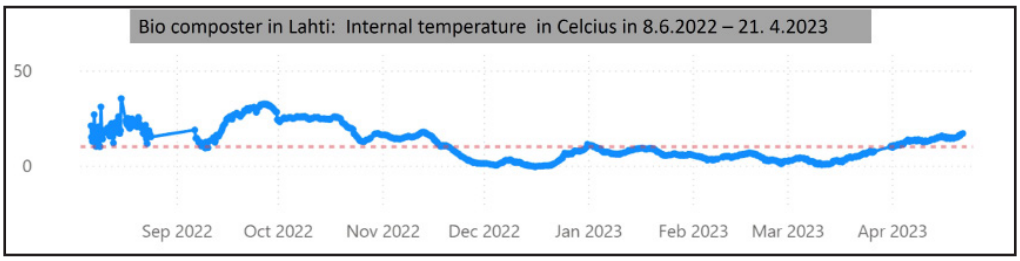
Comparison of three bio composters: The Power Bi application gathers the data of the three test bio composters into one view (Figure 7).

Households' self-assessment: Households' subjective assessment of what is the added value of the IoT sensor and data in the bio-composting process.

Biolan's self-assessment: Biolan Oy, as a solution owner, assesses the business potentiality

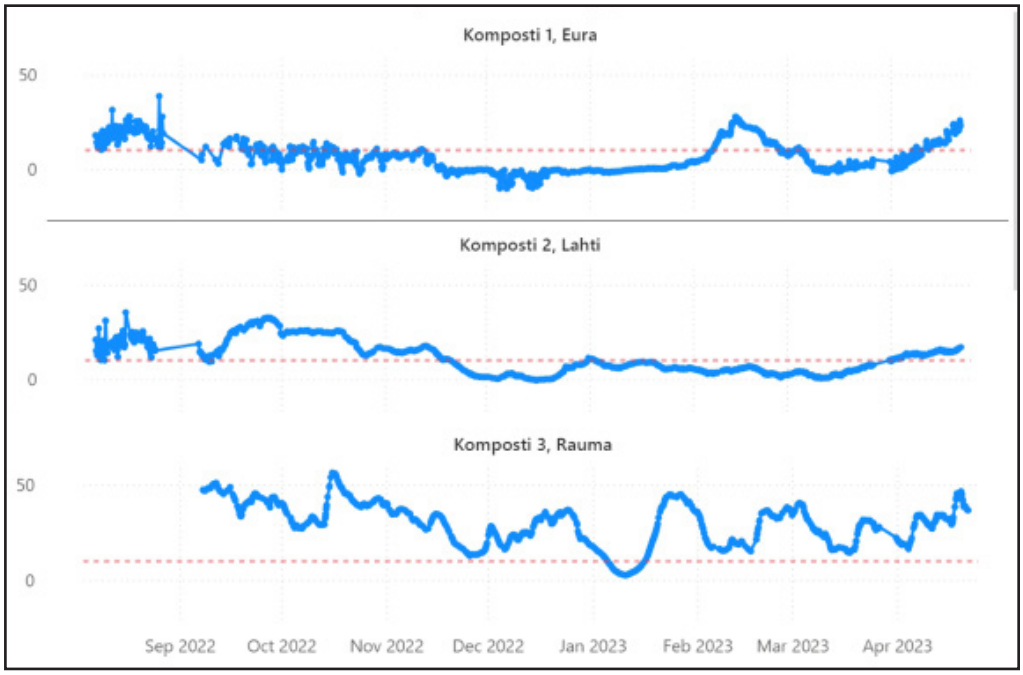
Source: Smart & Lean Hub Oy, Kalle Karlsson, PowerBi visualisation

Figure 5: Placemaking of bio composters and households that participate in the research.



Source: Smart & Lean Hub Oy, Kalle Karlsson, PowerBi visualisation

Figure 6: The long-time trend of the bio composter.



Source: Smart & Lean Hub Oy, Kalle Karlsson, PowerBi visualisation

Figure 7: Comparison of three bio composters temperature.

of the solution. The question is what is the payback time of the investment?

Stakeholders' assessment: The assessment took place in an online meeting. In addition, some stakeholders also gave feedback by email. In the meeting, the IoT sensor-equipped bio composter and associated solutions and applications (i.e., ICT architecture, mobile application, and Power Bi application) were shown and explained to stakeholders. The purpose was to assess the solution value and feasibility to ease public waste management authorities' work in the implementation and supervision of new waste law. Stakeholders were also urged to identify other potential users who could benefit from the solution. The waste management authorities and other stakeholders' consultative assessment and feedback are structured in the SWOT analysis format (see Table 1).

Mother Nature

Environment: In this research, the multi-actor approach is complemented by the fifth component of the Quintuple Helix Model (Carayannis et.al., 2012). The fifth component refers to environmental factors which influence the research and are influenced by the potential solutions.

Outdoor temperature: The external factor that impacts households' bio-composter performance is the outdoor temperature. In Finland, the bio-composter process slows down or totally stagnates in wintertime due to the low outdoor temperature. The best time for testing the bio-composter in Finland is hence from April to September.

Strengths New solution: An interesting solution, which did provoke some thoughts Green Deal: Collecting and transporting biowaste from smaller properties to centralized process utilities is not environmentally friendly. Composting at own premises is a better eco-deed. Value adding service: Gives the household new information and a new kind of service.	**Weakness** The solution does not facilitate the work of the waste management authority, where the main part is receiving basic information (name, address, etc.) and a composting notification from the composters. The solution is not suitable for all households that compost food waste. The authority is not able to focus on composting households so precisely. The task of the waste management authority is not to provide composting advice.
Opportunities Composting advice and guidance online: At its best, the solution offers households composting advice in a new way (algorithms, mobile application) The solution is suitable for pioneer users i.e., "digitally oriented engineers". The most potential target group are small house companies that have already received composting announcements. The introduction of remote monitoring can bring a competitive advantage and new services to the real estate maintenance company.	**Threats** Users' i.e. households ability to handle digital systems. Privacy policy. Households do not want to tell authorities or outsiders about composting. Negative experience of being "supervised by big brother".

Source: Smart & Lean Hub Oy, Kalle Karlsson, PowerBi visualisation

Table 1: SWOT-analysis of stakeholders' assessment and feedback.

Results and discussion

Method

Mission-oriented approach: The EC policies and consequent new waste management law in Finland, and Cities2030 objectives act as a driving force of the research. In addition, the Cities2030 project provided the proper environment for initiating and carrying out the research.

Testbeds: The three household testbeds worked well without any disruption (Figure 5). The installation of IoT sensors and the upload of mobile applications were easy and well-guided. The Biolan's ICT system worked fluently enabling continuous data collection. The number of testbeds is adequate to show the feasibility or problems of the prototype. In the case of Lahti, we extended the testbed to cover community waste management authorities' participation. They have shown interest in the study and ICT solution and even addressed 3 people to reflect and give feedback on the study. This is a positive sign because the implementation of the new waste law is in progress and public servants' resources are bound to it.

Lahti Living Lab: Lahti Living Lab is a framework that highlights open innovation, participation, problem-solving, and digitalization with and for the community. The framework worked well in the research, there were no contradictions. The Living Lab concept is neither odd nor unknown among stakeholders. This research communicates the better-known Living Lab concept both in Lahti and beyond.

Lean Startup: The Lean Startup methodology is practical and easy to adopt for experimental cases. Ideate-Build-Monitor-Learn phases assist to proceed systematically and logically. The internal documentation of the study is aligned with the methodology. The last phase of the Lean Startup, namely "Learn", also addresses the business modelling. In this case, the owner of the innovation and potential business is Biolan Oy. The business modelling is conducted internally at Biolan Oy.

SWOT analysis: The dialogues, reflection, and feedback from stakeholders deliver the SWOT analysis (Table 1). The observations and SWOT analysis are built upon individual people's comments and insights. They may give ideas for future pathways for stakeholders, but they do not provide a scientifically reliable result.

Responsible Research and Innovation (RRI), Ethics: GDPR and Consent Form are considered in relation to the participation of humans in the research. The ethics-related issues, such as "privacy policy" and "big brother supervision", were mentioned in the SWOT analysis. It is quite clear that they cause concern and thus an ethical code must be well prepared if the solution is taken into use. Multi-actor approach: The study applies a multi-actor approach that fosters a multi-

faced perspective into research reflection and supports public engagement and inclusion. Gender equity: The participants represent both genders in a balanced manner. Open access and transparency: Duringthe research the material is shared with participants openly via email and cloud-based platforms.

Science Education: The research not only demonstrates the pioneering digital technical solution but also raises awareness of opportunities, builds capacity, and transfers knowledge among participants. Governance: The main aim of the study is to advance eGovernment by demonstrating a feasible and operative digital solution.

Machine

Biolan bio-composter: There are no problems or breakdowns with the IoT-sensor-equipped bio-composter operation. It works quite well both in summer and winter.

Biolan system and data architecture: In the case of Biolan, end-users and PowerBi application designer's point of view is that the Biolan ICT system operated well. There are no detected problems or breakdowns.

Biolan mobile application: From the end-users' point of view, the Biolan ICT system worked well. No problems or breakdowns were detected. There are no detected problems or breakdowns.

The IoT-sensor-equipped bio-composter is technically a feasible solution. It is operational in real use and creates value for the household. The tested and assessed overall solution is one of the main results of the study.

Man

The research methodology is built upon multi-actor approach which means that we invite and engage into action multi-stakeholder members to enhance diverse points of view e.g., public bodies, companies, non-governmental organisations, and citizens. Based on monitoring data (see below in chapter "Measurement"), we succeeded to reach out a relatively large number of stakeholders (members). However, their interest and availability to participate in the research reach only a satisfactory level. Different projects and actions compete for the same people's attention. They cannot join in all and hence they have to prioritize their participation carefully.

Material

Household food waste: The different quality and quantity of household food waste and the differences in composter management practices are the main reasons for the variation between the three households (See Figure 7).

Food waste composting guidance: The data comparison raises questions and curiosity about what are the data-based best practices in bio-composter management. The data combined with composter management practices can generate a useful knowledge base for composting training for households.

Food waste composting guidance, namely Biolan's mobile application guidebook: Biolan delivers a guidebook for new mobile application users. It is an exploitable result of the research.

Measurement

Multi-actor participation: In the research time span, the engaged stakeholders represent public authorities, businesses, science & education, and households. Totally 27 people, most of them women (18), have been reached out to. 10 stakeholder members participated in the online consultative meeting, of which 4 were women. Personal contacts and the built community are the results of the study.

Bio composter temperature: For the end-user the long-term trend of the temperature is an interesting indicator. The graphic also shows how bio-composter treatments (e.g., emptying) impact the temperature. The analogue gauge does not receive the temperature as easily as the IoT sensor. The data is useful for the end-user but not necessarily vital to enhance bio-composter performance.

Comparison of the three bio-composters: The data visualisation indicates that data collection is successful, and there are no gaps in the data set. The data also show that the three bio-composters' temperatures and trends differ from each other's. Households' different composting practices and variations in competencies cause variations in bio-composter temperatures. However, in this study, the goal is not to analyse the causes of the variation. The temperature sensor is in the same place in the composter as the traditional analogue temperature gauge. Thus, the IoT-sensor measurement location is as good as it is in a traditional, version 0, bio-composter. This study

does not give an answer to the question if the IoT sensor temperature data are the same as with the measured analogue gauge or if there is a significant difference.

Households' self-assessment: The bio composter temperature data analysis is a value-adding element for some digital nerds, but necessarily it's not a tempting feature for all. Some households may benefit from the possibility of monitoring remotely the composter. For example, if the household possesses several bio composters in different locations, then remote monitoring could assist in keeping the composter on.

Biolan's self-assessment: Biolan Oy, as a solution owner, assesses the business potentiality of the solution and explores new product and service development ideas. The research is interesting and relevant from the bio-composter producer's point of view because the producer is eager to upgrade the bio-composter to the digital era and provide thus new services for their customers i.e. households and others. However, the SWOT analysis does not support solution development for public waste management authorities, instead, the needs of the real estate maintenance companies may be worth exploring.

Stakeholders' assessment: One result of the SWOT analysis is that waste management authority does not see value in the IoT-sensor-equipped bio composter for themselves. They do not envision associated eGovernment solutions. Authorities' attitude is that they will continue building a manual bio composter register, and audits on-site. On the other hand, the waste management authority is currently under pressure to cope with the new waste law implementation. Apparently, the timing is not right to introduce a new solution. Perhaps, in the future, the digitalised bio composter and eGovernment services that enable it are brought on the authorities' agenda.

In the researcher's opinion, the future is multi-faced: households will own both analogue and digital bio-composters. Thus, public authorities should adjust their activities accordingly. Both analogue and digital bio-composter supervision are doable options.

Real estate maintenance companies may be potential users of the solution. The digital mapping of composters and their remote monitoring may be useful for them and bring more efficiency.

Mother Nature

Households' bio-composting is a strength according to the SWOT analysis. In the researcher's opinion, municipality waste management authorities' task is to enhance the inhabitants' possibilities to be pro-environmental.

Conclusion

The IoT-sensor-equipped bio-composter is technically a feasible solution. It is operational in real use and creates value for the household. The most likely users among households are those who are data-driven and digitally oriented or who value the option of monitoring the bio-composter performance remotely.

Municipality waste management authorities do not consider the IoT-sensor-equipped solution beneficial from their perspective, although some households could be registered automatically and audited remotely by using the collected data.

Municipality waste management authorities do not consider the eGovernment policy and strategy is applicable in this case.

Participants considered that the study methods and process advanced awareness of food waste recycling, built capacity, and fostered knowledge exchange and transfer among stakeholders.

The remote mapping and monitoring of real estate bio composters could be a future tool for real estate maintenance companies.

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Iot-Sensor-Equipped Food Waste Bio-Composter to Households and to Advance Egovernment in Municipality Authorities' Waste Management Practices

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Abstract

Background: Finnish policymakers issued a new community waste law in 2022, that aims to increase household food waste recycling. The municipalities have launched the implementation of the waste law and are responsible for supervising the development of this new project.

Problem: The implementation and supervision of the waste law increases authorities' workload and also public costs. Public servants manage the households' compost register and carry out compost audits on-site.

Challenge: The challenge is to put in place the new waste management law at the lowest public cost.

Purpose: The research addresses the validation of a pioneering IT solution that supports and advances households' bio composting and aims to ease waste management authorities' workload by fostering eGovernment.

Methods: The intervention consists in delivering the IoT-sensor-equipped bio-composter and associated applications. The research adopts a mission-oriented approach, and establishes a place-based, multi-actor, participatory, and open innovation testbed at Living Lab. It leverages the Lean Startup process and SWOT analysis. The research method complies with the principles of Responsible Research and Innovation.

Conclusions: The IoT-sensor-equipped bio-composter is a feasible solution. Municipality waste management authorities do not regard/consider the IoT-sensor-equipped solution as beneficial from their perspective. The eGovernment strategy is not a driver in this case since bio-composter mapping and monitoring could be a future tool for real estate maintenance companies.

Keywords

Legislation, municipality, food waste, recycling, bio-composter, Living Lab, Internet of Things, eGovernment, city region, food systems.

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Introduction

In 2020, around 127 kilograms (kg) of food per inhabitant were wasted in the European Union (EU). Households generated 55% of food waste, accounting for 70 kg per inhabitant (EUROSTAT, 2022; EUROSTATa, 2023; EUROSTATb, 2023).

United Nations Sustainable Development Goal (SDG) number 12 is Responsible Consumption and Production. SDG target number 12.3 proposes to halve per capita global food waste at the retail and consumer levels by 2030 (FAOa, 2023; FAOb, 2023).

The European Commission is in the process of proposing legally binding targets to reduce food waste across the EU. The EU Waste Framework Directive 2023 will assess the feasibility of setting food waste reduction targets to implement the Union's commitments under the UN Sustainable Development Goals and the Farm to Fork

Strategy and limit the food supply chain's impact on the environment and climate. European Commission (EC) will inform the targets by the end of 2023 (ECa, 2023; ECc, 2023; ECd, 2023; ECe, 2023; ECf, 2023).

The waste reduction hierarchy includes prevention, preparing for reuse, recycling, recovery, and disposal. Preventing waste is the preferred option, and sending waste to landfill should be the last resort (EC, 2020).

This research addresses the recycling of Finnish households' food waste into new compost soil by using bio composting. Finnish households should improve their community waste collection and recycling, which, in 2020, covered merely 42 percent. EU countries' target for community waste recycling is 55 percent by 2025 and 65 percent by 2027. Finland's community waste keeps on increasing and the recycling rate is too low at this pace. Reaching the EU target looks far away. Under the circumstances, and as specified before, households must improve food waste separation from mixed waste to enable food waste recycling into new products (LUKE, 2021; Circwaste, 2022; Ympäristö, 2018; Hina et.al., 2022; Dhir et.al., 2020).

In 2021, the Finnish government updated the waste management law, with the aim of improving households' food waste recycling. It came into force this year (2023). Communities with more than 10,000 inhabitants are legally required to organize food waste collection (Finnish Ministry of Environment, 2021).

The new law increases inhabitants' general awareness of food waste value, and it emphasizes food waste separation from other household waste and recycling of food waste. The aim is to increase the quantity and quality of collected food waste to promote recycling. The industrial processes which produce biogas, compost soil, and biochar make use of collected food waste.

The new waste law also promotes households' small-scale bio-composting on their own premises. Composting reduces food waste transportation from households to centralized food waste processing units, which, in the long term, reduces household food waste management costs. Food waste composting outcome, which is compost soil, is a valuable resource for gardeners. Compost soil improves garden soil quality which, in turn, enhances growth and yield. Households' bio composting and gardening go very often hand-in-hand.

The new waste law requires that local waste management authorities keep a composter register on food waste. This register includes data on households that manage a bio-composter. Thus, the composter register assists authorities in watching and guiding the households' composting practices. Authorities can make compost audits of households, gather data on the households' quantity of food waste and its recycling, and record the data in the statutory composting register. Finally, the authorities use food waste data to calculate Finland's food waste recycling rate.

The implementation of the new waste management law inevitably increases e public costs. The public bodies and operators put effort into upkeeping the composter register, auditing households on site, and collecting data on waste food quantity. The waste management authorities and operators in the city region work with tax funds. They invoice the costs from the households via community waste billing. At the end of the day, the households will pay the increased community waste management costs. The payment takes place either through increased taxes or community waste bills.

The **problem** is that the implementation and supervision of the new waste law increase the authorities' work and public costs. Public servants manage the compost register, compost audits, and data collection. The **challenge** is to put in place the new waste management law with the lowest possible public service costs.

This means that the manner to build the composter register needs to be as automatic as possible. The amount of human work should be reduced to the minimum, which involves carrying out auditing sessions without physically going to households. The bio-composter auditors' work must be done remotely. This also means that the data collection on households' food waste recycling volume should be reconsidered, in terms of reducing manual workload in data collection to the minimum possible hours.

European Commission fosters transition to effective digital public services and eGovernment, which develops smart tools, rethinking organisations and processes, and changing behaviour so that public services are delivered more efficiently to people (EC eGovernment, 2023).

The key intervention in the research is an IT architecture and application. The IT solution, which is associated with food waste bio composter, is pioneering. The IoT sensors and LoRaWan technology have not before been introduced

and piloted in the context of households‘ food waste bio composting (Digita, 2023).

In this research, three households in Finland test an IoT-sensor-equipped bio composter, which leverages LoRaWan technology for data transfer.

Further, the municipality waste management authorities and other biowaste collection and recycling-related stakeholders were invited to participate in the research action. Their role was to assess and give feedback on IoT-sensor-equipped bio composter taking into account the new waste management law requirements and consequent new tasks for municipalities.

The research questions are as follows:

RQ1: What is IoT-sensor-equipped bio-composter feasibility?

RQ2: What kind of weaknesses, strengths, opportunities, and threats do the involved households, the product owner (Biolan Oy), public waste management authorities, and other stakeholders envision in the IoT-sensor-equipped bio-composter uptake and execution?

Materials and methods

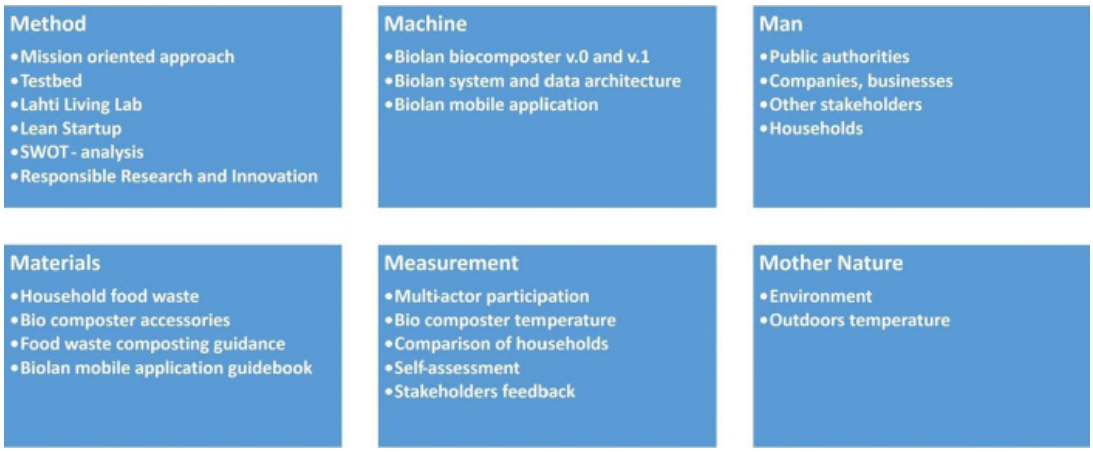
The research framework includes six elements, namely: method, machine, man, material, measurement, and mother nature. Figure 1 outlines the main sub-variables for each element, and every element is analysed in this chapter.

Method

The purpose of this applied science research is to test and assess the pioneering IT solution whose aim is to ease public waste management authorities' bio-composting-related tasks in households and foster eGovernment. The research applies a wide range of approaches and methods that are mission-oriented, place-based, multi-actor, participatory, open innovation, structured, analytical, and ethical.

Mission-oriented approach: The research aim is to contribute to the European Commission’s vision and objectives, namely Food 2030 policy via innovation actions that are conducted in the Horizon2020 project Cities2030 (Cities2030, 2020). The main missions of the Food 2030 policy are as follows: 1) Nutrition for sustainable and healthy diets. 2) Food systems supporting a healthy planet. 3) Circularity and resource efficiency. 4) Innovation and empowering communities. This research contributes to the third and fourth missions (ECb, 2023). The research also contributes to achieving the specific objective of the Cities2030 project i.e. "Enhance circularity and local food belts". The research responds to the challenge of promoting the circulation of nutrients contained in urban household food waste from the table back to the soil.

Testbeds: Three households tested the solution on their own premises in Eura, Rauma, and Lahti. Further, one of the testbeds invited the municipality waste management authorities to join in and assess, respectively, provide feedback on the solution. This extended testbed was established in the city of Lahti. Lahti is a city of 120,000 inhabitants and about 31,000 households. Lahti is located in southern Finland, in the county of Päijät-Häme. The local community waste management operator is Salpakierto Oy, that is responsible for implementingt the waste management law. Lahti municipality waste management authorities control



Source: Smart & Lean Hub Oy, Tuula Löytty

Figure 1: Research framework

and guide Salpakierto's processes and performance. Salpakierto food waste management experts have estimated the number of households' composters and, accordingly, 10-15% of Lahti households own a bio-composter. This means that Salpakierto Oy will register and audit at least 3,100 households in the city of Lahti (Salpakierto, 2021; Salpakierto, 2023).

Lahti Living Lab: Cities2030 project fosters urban food system transformation by carrying out innovation actions e.g., experiments and capacity-building actions in a local setting. The operational multi-actor platforms for innovation actions are place-based Living Labs. Living Labs' aim is to generate innovations and empower multi-stakeholder communities in an open innovation environment. Lahti Living Lab from Finland is part of the Cities2030 labs, and contributes to achieving the Lahti Vision 2030, namely "Lahti is a sustainable and carbon neutral city region". Lahti Living Lab is a multi-actor, participatory, and open innovation environment and testbed for IoT-sensor-equipped bio-composter (Lahti Living Lab, 2023; Bogers et.al, 2017; Hirvikoski et.al, 2020).

Lean Startup: The research procedure applies the Lean Startup methodology, which is based on the following concepts: Ideate - Build - Monitor - Learn. The Ideate phase is dedicated to planning the research procedure. The building phase is twofold: a) food waste bio composter preparation in the test site and b) ICT architecture, sensor-, IoT- and data collection and architecture solutions at Biolan Oy. The monitoring takes place in three steps: Biolan Oy's self-assessment, households' self-assessment, and waste management authorities and bio waste stakeholders' consultative assessment and feedback. The last phase, i.e. Learning purpose, is to answer to following business and proposed questions: "Does this product serve as a solution to the set challenge?" "Should this product be built?" and "Can we build a sustainable business around this set of products and services?" (Lean Startup, 2023).

SWOT-analysis: SWOT analysis is a brainstorming tool that facilitates participants' communication and assessment on the topic regarding current strengths and weaknesses and future opportunities and threats as well. The waste management authorities and stakeholders' consultative assessment and feedback are included in the SWOT analysis (Benzaghta et al., 2021).

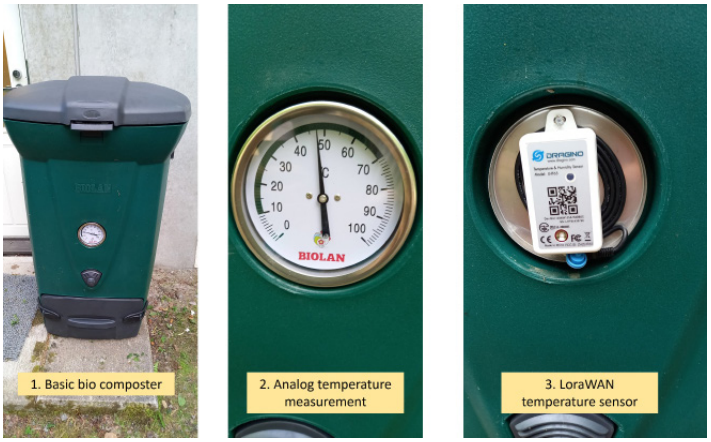
Responsible Research and Innovation (RRI): The research is conducted as a part of Cities2030 project which is funded by EC's Horizon 2020 program. Cities2030 delivers a project RRI framework to contribute to the EC's vision of an inclusive, innovative, and reflective society. The basic RRI toolkit comprises 6 themes: Ethics, Gender Equality, Governance, Open Access, Public Engagement, and Science Education (RRI, 2023). The purpose of the Cities2030 project is to ideate, co-create, implement, and pilot RRI tools and concepts under research and innovation actions, which are meant to structure a Cities2030 RRI framework for the responsible co-creation, pilot, and deployment of innovations.

Machine

The Machine - element refers to facilities, systems, tools, and pieces of equipment employed for the research.

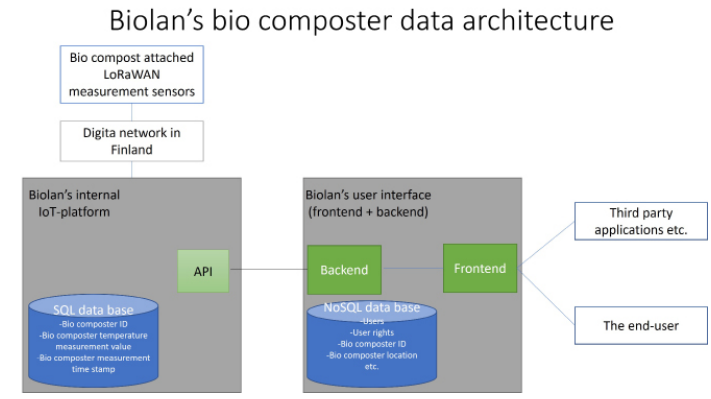
Biolan bio composter: Biolan Oy is a Finnish family business specialising in developing, manufacturing, and marketing products that help reduce the environmental impact of daily human activities (Biolan, 2023). The basic bio composter, version 0, which is addressed particularly to households is a Biolan Quick Composter 220eco. It is equipped with an analogue temperature measurement (see Figure 2). Biolan Oy developed the first version of the digital sensor-equipped bio-composter in 2018-2019. The idea was to substitute the analogue temperature gauge with a digital sensor to enable continuous temperature monitoring in the bio-composter, and to connect the bio-composter to the internet. It was a pilot of an Internet of Things (IoT) solution. At that time, data transfer become a barrier and thus Biolan Oy left the idea aside for a couple of years. In 2022, Biolan Oy picked up on the old concept and upgraded it to exploit LoRaWAN technology by using DRAGINO's LHT65 LoRaWAN temperature sensor (see Figure 2). One IoT sensor costs about 50 EUR. The LoRaWAN technology has become one of the key enabling technologies for the development of Internet of Things architectures. It has been very popular and useful in Smart City applications, including public waste management (Biolan, 2023; DRAGINO, 2023; Baldo et.al., 2021; Cruz et.al., 2021).

The first version of Biolan's bio composter is pioneering. The IoT sensors and LoRaWAN technology have not been introduced and piloted before in the context of households' food waste bio composting.



Source: Smart & Lean Hub Oy, Tuula Löytty

Figure 2: 1. Basic bio composter; 2. Analogue temperature measurement; 3. LoRaWAN temperature sensor.

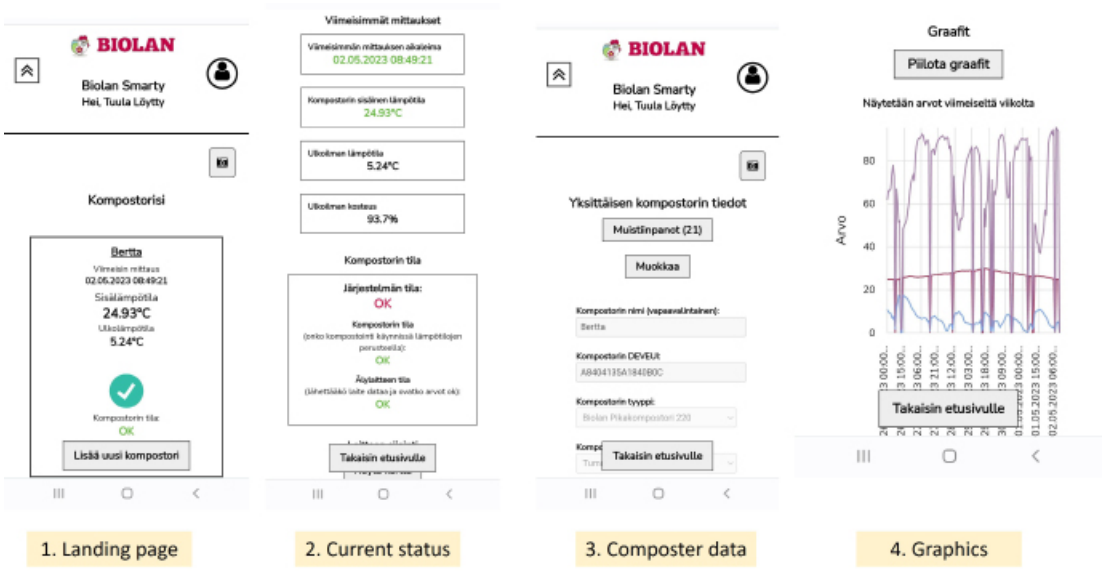


Source: Biolan Oy, Sami Rantamäki

Figure 3: Biolan's system and data architecture schema.

Biolan system and data architecture: Data collection was done utilising sensors connected to composts. Sensors send data every 15 minutes to Biolan SQL-database (System Query Language) through the Internet (Figure 3). In SQL-database, the data coming from the composter IoT-sensors is made into tables in SQL-database. This means that the sensor data is normalised into constructional data which can be easily used in reporting or other applications. Data from sensors is send first to SQL-database instead of directly sending it to programs that utilise the data. This is done because it is easier to control the users of the data, it's easier to share the data to applications which utilise the data in their work and apply additional layer of cyber security. Utilising SQL-database between the IoT-sensor and the applications crates a master database and guarantees that different applications which utilise IoT-sensor are all using the same data from the master database.

Table columns are visualized in Figure 4. After data normalization, data is moved through API (Application Programming Interface) into another database. This is done to prevent end-users and third-party applications from accessing the master database. From NoSQL database composter data is then spread to end-users and into third-party applications, such as Power BI (Figures 6 and 7).



Source: Biolan Oy, Bioapps-application, Sami Rantamäki

Figure 4: Screenshot of Biolan's mobile application.

Man

The Man-element refers to all operative and participating people who are involved and contribute to the delivery of a process and accompanied research. The people represent policymakers, public authorities, businesses, education, science, and households. The term "Man" does not refer to gender, quite the opposite, the gender-balanced research is one of the aims. The research complies with the multi-actor approach in human participation (EIP-Agri, 2017), and establishes a multi-actor stakeholder community to facilitate knowledge exchange and transfer, capacity building and innovation actions, as well as networking among bio- and food waste stakeholders.

Public authorities: The extended solution testbed was established in the city of Lahti, under the wings of Lahti Living Lab. The waste management authorities of the city of Lahti are responsible for implementing and monitoring the new waste law in the city. Authorities establish the compost record, audit households composting practices, and collect data for European Commission about food waste recycling in the region. The aim of the study is to facilitate and easy waste management authorities work with a new approach. Lahti's waste management authorities represent and give a voice to all regional waste management authorities and operators, although from a scientific perspective, their feedback and insight into the solution are not representative. In 2022, 31 regional waste management authorities and operators were mapped in Finland (Karlsson-b, 2022). They are responsible actors for community waste management in all 220 municipalities of Finland.

Companies and businesses: Biolan Oy is a Finnish family-owned SME company whose main products are bio composters, associated goods, and consumables. Biolan Oy owns the intellectual property rights of the IoT sensor-equipped bio composter. Their interest is to extend their market share via new innovative services (Biolan, 2023).

Other stakeholders: Households' biowaste management in Finland interests a wide group of stakeholders, namely actors that are on bio-composting goods and consumables, guidance, logistics, law, regulation, and EU communication. There are also some associations that work for the inhabitants' benefit giving advice and support. And there is a large group of institutions, organizations, associations, entities, and projects that provide services on education, advisory, research, development, innovations, and data.

Households: This study engaged three households willing to test IoT-sensor-equipped bio-composters. The households are located in Lahti, Eura, and Rauma. Eura and Rauma bio composters are internal to Biolan Oy, meaning that the actors are working for Biolan Oy. The household in Lahti is the first external user of Biolan Oy's solution.

Figure 5 shows the mapping of the place of households that took part in the research. The localisation and visualization take place based on Biolan's mobile application registration data.

Materials

Household food waste: The household's normal food waste is the raw material for bio composter process e.g., fruit and vegetable peels, meat and fish waste, etc. food residues, coffee and tea reindeer with filter bags, old flower soil and plant waste, soft and moist papers, crushed eggshells, natural fibers in small pieces.

Bio composter accessories: To maintain and speed up the composting process ongoing, it's possible to add now and then accessories such as composting accelerator and bulking material.

Food waste composting guidance: Although composting is not difficult, it's beneficial for newcomers to familiarize themselves with the procedures of bio-composting. The Internet provides a lot of information on such practices. One reliable source is the bio-composter producers' web page (Biolan, 2023).

Biolan's mobile application guidebook: Biolan delivered a guidebook for the users of the new mobile application. It provides detailed guidance on how households can independently register themselves as a user of the solution and how to further use the mobile application.

Measurement

This chapter addresses the issues of research monitoring and measurement systems.

Multi-actor participation: The goal was to build a multi-actor environment to test and assess the IoT-sensor-equipped bio-composter. To that end, stakeholder reach-out and engagement measures were documented and measured: how many stakeholder members were contacted, what was the typification of the stakeholder, and what was the gender of the stakeholder member. Only one person in this study was responsible for stakeholder engagement and management, and thus the measurement system is considered reliable and traceable.

Bio-composter temperature: As already explained in the chapter Machine, the IoT-sensor equipped bio-composter enables remote monitoring of the bio-composter inside temperature. The collected data is visualised in the mobile application and also in the Power Bi application. The mobile application shows a short time frame of about 12 days. The Power Bi application shows a long-time trend starting from the beginning of August 2022 (Figure 6) (Karlsson-a, 2022).

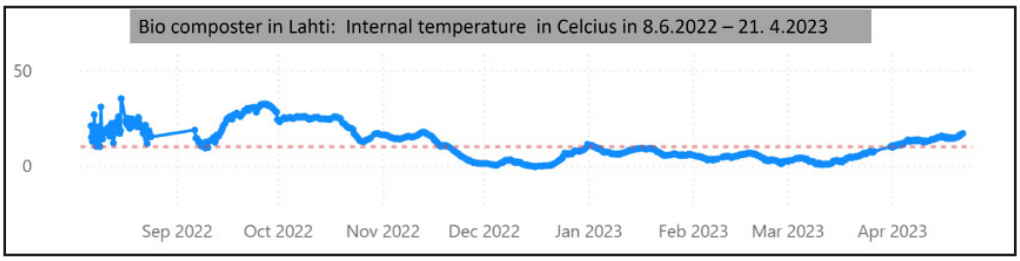
Comparison of three bio composters: The Power Bi application gathers the data of the three test bio composters into one view (Figure 7).

Households' self-assessment: Households' subjective assessment of what is the added value of the IoT sensor and data in the bio-composting process.

Biolan's self-assessment: Biolan Oy, as a solution owner, assesses the business potentiality

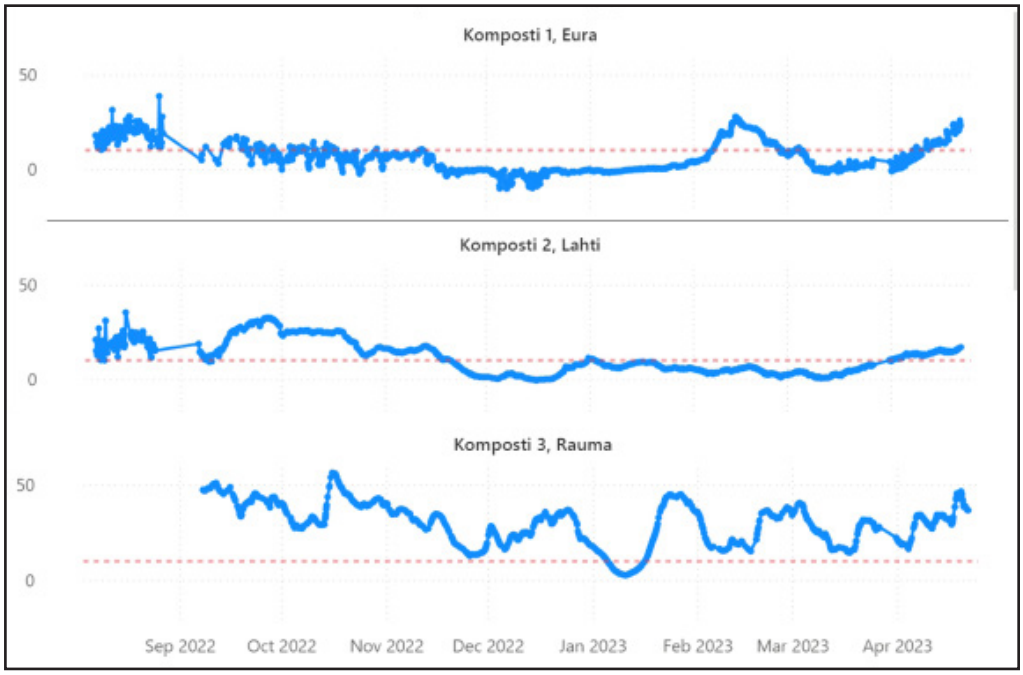
Source: Smart & Lean Hub Oy, Kalle Karlsson, PowerBi visualisation

Figure 5: Placemaking of bio composters and households that participate in the research.



Source: Smart & Lean Hub Oy, Kalle Karlsson, PowerBi visualisation

Figure 6: The long-time trend of the bio composter.



Source: Smart & Lean Hub Oy, Kalle Karlsson, PowerBi visualisation

Figure 7: Comparison of three bio composters temperature.

of the solution. The question is what is the payback time of the investment?

Stakeholders' assessment: The assessment took place in an online meeting. In addition, some stakeholders also gave feedback by email. In the meeting, the IoT sensor-equipped bio composter and associated solutions and applications (i.e., ICT architecture, mobile application, and Power Bi application) were shown and explained to stakeholders. The purpose was to assess the solution value and feasibility to ease public waste management authorities' work in the implementation and supervision of new waste law. Stakeholders were also urged to identify other potential users who could benefit from the solution. The waste management authorities and other stakeholders' consultative assessment and feedback are structured in the SWOT analysis format (see Table 1).

Mother Nature

Environment: In this research, the multi-actor approach is complemented by the fifth component of the Quintuple Helix Model (Carayannis et.al., 2012). The fifth component refers to environmental factors which influence the research and are influenced by the potential solutions.

Outdoor temperature: The external factor that impacts households' bio-composter performance is the outdoor temperature. In Finland, the bio-composter process slows down or totally stagnates in wintertime due to the low outdoor temperature. The best time for testing the bio-composter in Finland is hence from April to September.

Strengths New solution: An interesting solution, which did provoke some thoughts Green Deal: Collecting and transporting biowaste from smaller properties to centralized process utilities is not environmentally friendly. Composting at own premises is a better eco-deed. Value adding service: Gives the household new information and a new kind of service.	**Weakness** The solution does not facilitate the work of the waste management authority, where the main part is receiving basic information (name, address, etc.) and a composting notification from the composters. The solution is not suitable for all households that compost food waste. The authority is not able to focus on composting households so precisely. The task of the waste management authority is not to provide composting advice.
Opportunities Composting advice and guidance online: At its best, the solution offers households composting advice in a new way (algorithms, mobile application) The solution is suitable for pioneer users i.e., "digitally oriented engineers". The most potential target group are small house companies that have already received composting announcements. The introduction of remote monitoring can bring a competitive advantage and new services to the real estate maintenance company.	**Threats** Users' i.e. households ability to handle digital systems. Privacy policy. Households do not want to tell authorities or outsiders about composting. Negative experience of being "supervised by big brother".

Source: Smart & Lean Hub Oy, Kalle Karlsson, PowerBi visualisation

Table 1: SWOT-analysis of stakeholders' assessment and feedback.

Results and discussion

Method

Mission-oriented approach: The EC policies and consequent new waste management law in Finland, and Cities2030 objectives act as a driving force of the research. In addition, the Cities2030 project provided the proper environment for initiating and carrying out the research.

Testbeds: The three household testbeds worked well without any disruption (Figure 5). The installation of IoT sensors and the upload of mobile applications were easy and well-guided. The Biolan's ICT system worked fluently enabling continuous data collection. The number of testbeds is adequate to show the feasibility or problems of the prototype. In the case of Lahti, we extended the testbed to cover community waste management authorities' participation. They have shown interest in the study and ICT solution and even addressed 3 people to reflect and give feedback on the study. This is a positive sign because the implementation of the new waste law is in progress and public servants' resources are bound to it.

Lahti Living Lab: Lahti Living Lab is a framework that highlights open innovation, participation, problem-solving, and digitalization with and for the community. The framework worked well in the research, there were no contradictions. The Living Lab concept is neither odd nor unknown among stakeholders. This research communicates the better-known Living Lab concept both in Lahti and beyond.

Lean Startup: The Lean Startup methodology is practical and easy to adopt for experimental cases. Ideate-Build-Monitor-Learn phases assist to proceed systematically and logically. The internal documentation of the study is aligned with the methodology. The last phase of the Lean Startup, namely "Learn", also addresses the business modelling. In this case, the owner of the innovation and potential business is Biolan Oy. The business modelling is conducted internally at Biolan Oy.

SWOT analysis: The dialogues, reflection, and feedback from stakeholders deliver the SWOT analysis (Table 1). The observations and SWOT analysis are built upon individual people's comments and insights. They may give ideas for future pathways for stakeholders, but they do not provide a scientifically reliable result.

Responsible Research and Innovation (RRI), Ethics: GDPR and Consent Form are considered in relation to the participation of humans in the research. The ethics-related issues, such as "privacy policy" and "big brother supervision", were mentioned in the SWOT analysis. It is quite clear that they cause concern and thus an ethical code must be well prepared if the solution is taken into use. Multi-actor approach: The study applies a multi-actor approach that fosters a multi-

faced perspective into research reflection and supports public engagement and inclusion. Gender equity: The participants represent both genders in a balanced manner. Open access and transparency: Duringthe research the material is shared with participants openly via email and cloud-based platforms.

Science Education: The research not only demonstrates the pioneering digital technical solution but also raises awareness of opportunities, builds capacity, and transfers knowledge among participants. Governance: The main aim of the study is to advance eGovernment by demonstrating a feasible and operative digital solution.

Machine

Biolan bio-composter: There are no problems or breakdowns with the IoT-sensor-equipped bio-composter operation. It works quite well both in summer and winter.

Biolan system and data architecture: In the case of Biolan, end-users and PowerBi application designer's point of view is that the Biolan ICT system operated well. There are no detected problems or breakdowns.

Biolan mobile application: From the end-users' point of view, the Biolan ICT system worked well. No problems or breakdowns were detected. There are no detected problems or breakdowns.

The IoT-sensor-equipped bio-composter is technically a feasible solution. It is operational in real use and creates value for the household. The tested and assessed overall solution is one of the main results of the study.

Man

The research methodology is built upon multi-actor approach which means that we invite and engage into action multi-stakeholder members to enhance diverse points of view e.g., public bodies, companies, non-governmental organisations, and citizens. Based on monitoring data (see below in chapter "Measurement"), we succeeded to reach out a relatively large number of stakeholders (members). However, their interest and availability to participate in the research reach only a satisfactory level. Different projects and actions compete for the same people's attention. They cannot join in all and hence they have to prioritize their participation carefully.

Material

Household food waste: The different quality and quantity of household food waste and the differences in composter management practices are the main reasons for the variation between the three households (See Figure 7).

Food waste composting guidance: The data comparison raises questions and curiosity about what are the data-based best practices in bio-composter management. The data combined with composter management practices can generate a useful knowledge base for composting training for households.

Food waste composting guidance, namely Biolan's mobile application guidebook: Biolan delivers a guidebook for new mobile application users. It is an exploitable result of the research.

Measurement

Multi-actor participation: In the research time span, the engaged stakeholders represent public authorities, businesses, science & education, and households. Totally 27 people, most of them women (18), have been reached out to. 10 stakeholder members participated in the online consultative meeting, of which 4 were women. Personal contacts and the built community are the results of the study.

Bio composter temperature: For the end-user the long-term trend of the temperature is an interesting indicator. The graphic also shows how bio-composter treatments (e.g., emptying) impact the temperature. The analogue gauge does not receive the temperature as easily as the IoT sensor. The data is useful for the end-user but not necessarily vital to enhance bio-composter performance.

Comparison of the three bio-composters: The data visualisation indicates that data collection is successful, and there are no gaps in the data set. The data also show that the three bio-composters' temperatures and trends differ from each other's. Households' different composting practices and variations in competencies cause variations in bio-composter temperatures. However, in this study, the goal is not to analyse the causes of the variation. The temperature sensor is in the same place in the composter as the traditional analogue temperature gauge. Thus, the IoT-sensor measurement location is as good as it is in a traditional, version 0, bio-composter. This study

does not give an answer to the question if the IoT sensor temperature data are the same as with the measured analogue gauge or if there is a significant difference.

Households' self-assessment: The bio composter temperature data analysis is a value-adding element for some digital nerds, but necessarily it's not a tempting feature for all. Some households may benefit from the possibility of monitoring remotely the composter. For example, if the household possesses several bio composters in different locations, then remote monitoring could assist in keeping the composter on.

Biolan's self-assessment: Biolan Oy, as a solution owner, assesses the business potentiality of the solution and explores new product and service development ideas. The research is interesting and relevant from the bio-composter producer's point of view because the producer is eager to upgrade the bio-composter to the digital era and provide thus new services for their customers i.e. households and others. However, the SWOT analysis does not support solution development for public waste management authorities, instead, the needs of the real estate maintenance companies may be worth exploring.

Stakeholders' assessment: One result of the SWOT analysis is that waste management authority does not see value in the IoT-sensor-equipped bio composter for themselves. They do not envision associated eGovernment solutions. Authorities' attitude is that they will continue building a manual bio composter register, and audits on-site. On the other hand, the waste management authority is currently under pressure to cope with the new waste law implementation. Apparently, the timing is not right to introduce a new solution. Perhaps, in the future, the digitalised bio composter and eGovernment services that enable it are brought on the authorities' agenda.

In the researcher's opinion, the future is multi-faced: households will own both analogue and digital bio-composters. Thus, public authorities should adjust their activities accordingly. Both analogue and digital bio-composter supervision are doable options.

Real estate maintenance companies may be potential users of the solution. The digital mapping of composters and their remote monitoring may be useful for them and bring more efficiency.

Mother Nature

Households' bio-composting is a strength according to the SWOT analysis. In the researcher's opinion, municipality waste management authorities' task is to enhance the inhabitants' possibilities to be pro-environmental.

Conclusion

The IoT-sensor-equipped bio-composter is technically a feasible solution. It is operational in real use and creates value for the household. The most likely users among households are those who are data-driven and digitally oriented or who value the option of monitoring the bio-composter performance remotely.

Municipality waste management authorities do not consider the IoT-sensor-equipped solution beneficial from their perspective, although some households could be registered automatically and audited remotely by using the collected data.

Municipality waste management authorities do not consider the eGovernment policy and strategy is applicable in this case.

Participants considered that the study methods and process advanced awareness of food waste recycling, built capacity, and fostered knowledge exchange and transfer among stakeholders.

The remote mapping and monitoring of real estate bio composters could be a future tool for real estate maintenance companies.

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