How Can Design Thinking and Lean Startup Improve Waste Collection Systems?

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Abstract

The collective idea of smart cites appeared as a modern urban development vision to optimise the management of city infrastructures and services by combining Information and Communication Technology (ICT) and Internet of Things (IoT). Alongside the technological advancements, the expansion of urban areas has set new scenarios, problems and challenges within the municipal and metropolitan contexts which inevitably require innovative ways to help local governments improve their citizens' lives. Waste management stands as one major issues to face and within this waste collection systems (WCS) commonly represents the most impactful phase. This paper presents an hybrid methodology combining Design Thinking and Lean Startup to provide a holistic and deep understanding of the various WCS processes to subsequently develop a viable and innovative solution to better respond the municipality's economic and operational needs. The researchers conducted an empirical application throughout a case study within the WCS context of a European municipality that recently embraced a smart city initiative following the proposed methodological stages, framed in the problem-solution space, by collecting wide range of data, together with the solution exploration and fine-tuning. It has been concluded that the hybrid approach provides both rich understanding of the problem space while minimizing implementation risks.

Keywords: Smart City, Internet of Things, Design Thinking, Lean Startup, Smart Waste Collection Systems

1. Introduction

During the latest years, the fast-technological improvement has literally affected our daily lives, activities and social contexts. The growth rate of innovations and digitalization has involved all sectors, resulting systematically in an increasing impact on businesses, daily activities as well as urban settings. The development of smart hi-tech devices and fast connections, alongside a widespread employment of the internet, led our world to an unprecedented global revolution which is changing, and still will change, our society, including our cities and their overall organization.

In parallel with the technological advancements, the big expansion of human population and consequent urbanization has set new scenarios, problems and challenges within the municipal and metropolitan contexts which inevitably require new innovative ways to help local governments improve their citizens' lives. The collective idea of "city of the future", intelligent city or smart city (SC), has affirmed itself as a modern urban development vision to optimise the daily management of city infrastructures and services through a combination of ICT (Information and Communication Technology) and IoT (Internet of Things) technologies (Karadağ, T., 2013, Jardim-Goncalves et al., 2013). The concept of smart city, appeared in the beginning of the 1990s as an evidence of how urban development was changing its target towards technology, innovation and globalization (Schaffers et al., 2011), embracing the idea of a sustainable, efficient and innovative city, capable of guaranteeing a high quality of life for its citizens thanks to the use of connected and integrated solutions and technological systems.

However, within the increasing urbanization phenomenon and in parallel with the higher consumption habits, waste management (WM) stands as one of the major global issues that governments face on their daily basis, being regarded as one of the crucial utility services underpinning society in the 21st century, especially when it comes to urban areas (Demirbas, 2011). In fact, the overproduction of waste has been causing negative impacts on people health and our environment and, as such, waste reduction as well as its valorisation need to be taken to the next level. Despite some possible peculiarities among different countries, the municipal solid waste (MSW), as waste generated by households, emerges as a complex key point within the overall city's ecosystems (Nguyen et al., 2009). It has to be managed when generated, handled according to different waste categories, collected, transferred and transported by proper trucks to the treatment facilities or dumping sites, processed and treated, and eventually recycled before being disposed when recycling is no longer possible (Wilson et al., 2015; Aleluia et al., 2016). Even if each step of this value-chain has its own characteristics in terms of activities, maintenance as well as budgeting, it is commonly recognized that the collection, transfer and transportation phase, also known as waste collection system (WCS), represents the most impactful and weighted stage from an operational, economic and environmental point of view. In fact, it implies: major risks for citizens health and the environment preservation; more managerial complexities, especially in bigger cities; and greater expenses, counting approximately 50% of the total MSW costs (Kaza et al., 2018).

Thanks to the modern technologies and smart solutions such as the IoT, a smart waste collection system (SWCS) within a SC context could represent a valid support to better handle this issue and find more efficient and optimized solutions for decision-making. Considering the social, environmental and the monetary cost that the massive waste production increase, the rapid urbanization and the forecasted population growth portray for municipalities, it becomes necessary identifying all the main weak points affecting the waste management system to study the most relevant problems and find out innovative solutions. Taking into account that the major weaknesses emerging in the collection, transfer and transportation phase of the MSW value-chain as a main motivation to be deepen, the present paper is intended to focus the attention on the aforementioned gap in order to conduct, throughout the development of a case study, a real investigation on the reported WCS issue. As such, the objective of this paper is to propose an innovative hybrid methodology that combines the Design Thinking (DT) and Lean Startup (LS) approaches to a complex problem environment and develop new digital solutions to create SWCS prototypes. This latter is intended to provide:

- An overall view of the WCS operational context within an environment composed by various stakeholders;
- A holistic but coherent definition of the specific problem-space to have as a general basis to further ideate in a co-creation and collaborative environment;
- Smart and digital solutions for the municipality's stakeholders to effectively enhance WCS activities;
- Validate the DT and LS outputs that are often seen as emotional and subjective to conventional organizations.

The suggested methodology has been performed within the real-life context by applying a case study research methodology on the waste collection system (WCS) of a European municipality that had recently embraced a SC project, currently being developed by a multinational consulting company wherein the authors were integrated. The application of this latter allowed the researchers to test numerous tools and techniques throughout the holistic process and consequently be able to critically evaluate the various advantages and drawbacks of it.

This paper is structured as follows: In section 2 provides a theoretical review on the topics of Design Thinking and Lean Startup; Section 3 presents the proposed hybrid methodology combining DT and LS; In section 4 it is described the case study where the methodology was applied; Conclusions of the research are presented in section 5.

2. Theoretical Review

The fundamental basis of this paper theoretical review is taken from two main research topics: Design Thinking (DT) and the Lean Startup (LS). Here, these two business methodologies were explored so that they could be combined to provide an adequate solution for the WCS issues found in the municipality in study and tackle the inherent limitations imposed by each theory. Hence, the researchers primarily summarizes each theory's pros and cons on Figure 1.

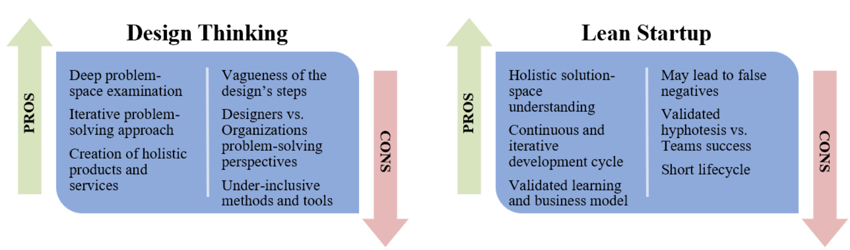

Figure 1. Strengths and weaknesses of Design Thinking and Lean Startup methodologies

As above mentioned, there are both advantages and drawbacks concerning the application of Design Thinking and Lean Startup methodologies. In respect to Design Thinking, this methodology provides a holistic view to the problem-space understanding, where it tours (in an iterative way) the problem-solution framing and consequent validation, taking always into account the various costumers needs (Tschimmel, 2012). However, there are certain limitations that should be considered. For instance, some authors alert for DT under-inclusive and subjective nature in terms of not following an orderly sequence of steps, negatively impacting the design of more conventional business' milestones. In addition, there are still huge differences between designers and managers mentalities for solving problems, often leading to disagreements and misconceptions about the methods or tools applied in business projects (Brown, 2008; Liedtka, 2011; Efeoglu, 2014).

On the other side, Lean Startup is more focused on the solution-space exploration, enhancing innovation through a continuous cycle of validated experimentation wherein a set of minimum viable products are iteratively adapted to the market needs, helping organizations and managers increasing their success when searching for a sustainable and viable business model, without having the need of spending a great amount of money and resources (Ries, 2011; Harms et al., 2015). Notwithstanding, many critics defend a non-linear relationship between the number of validated hypothesis and the subsequent team success when developing a new product or service, emphasising that validation does not always convert into success. Moreover, incorrect data may invalidate the hypothesis, which may lead to pivoting (eliminate) good ideas into "false negatives" (Ladd, 2016). At last, LS methodology requires too much prototyping and testing given its shorten lifecycle, which could translate in additional economic efforts (Ghezzi et al., 2018).

Ultimately, the researchers suggested a mix between the DT and LS methodologies to enhance the creation of a successful SWCS within the SC context in study. On the other hand, despite both strategies share similar goals, each strategy has its particular target group and focus on specific requirements, which means that it is not recommended to interchange between methodologies arbitrarily. In addition, this reflects an opportunity for learning and complement from each other method, once they both involve distinct features that the other strategy is not bearing in mind, but might be useful.

3. Proposed Hybrid Methodology

In the light of the analysis of the two methodological approaches, wherein the perceived DT and LS strategies benefits and limitations were explored, the authors could now propose a new methodology that combines the central aspects of each one of the two innovation strategies. This proposed adaptation of DT and LS merges the most favourable steps of both strategies and at the same time tackles the identified gaps, complementing one another harmoniously. Hence, it was proposed the model in Figure 2, highlighting the respective features, adjusted from the original methodologies.

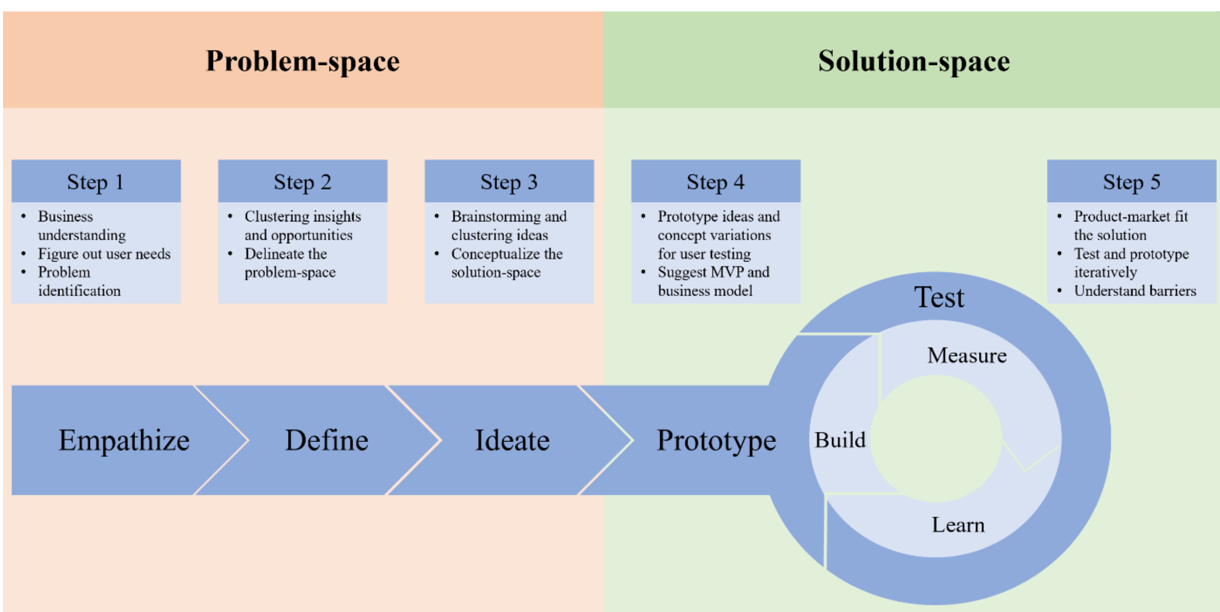

Figure 2. Suggested model of Design Thinking and Lean Startup

Despite the suggested diagram representing a single procedure, it can be divided in two different sections: the problem-space and the solution-space. This division offers the users that will apply it, a fresh new way of thinking about the Design Thinking and Lean Startup methodologies, as constituent parts of a greater innovation strategy. Additionally, while the problem-space depicts wherein user's needs live, the solution-space portrays where the products/services and experiments that satisfy the user's needs reside. As pictured on Figure 2 the proposed DT and LS model can be divided in five different steps.

Starting with the **Step 1 (Empathize)**, it is important to perform a number of qualitative research analysis to have a holistic view of the business in question and better understand the various stakeholders' needs and interactions. Once the user's needs are identified, it is now possible to explore and frame the problem-space. The **Step 2 (Define)**, gathers the various insights obtained in the previous stage and then clusters into a visual framework. Despite this step representing a DT phase, the authors proposed the introduction of metric-based evaluation techniques from the LS methodology to allow a quantitative measurement of customers feedback. This is where the multiple observations are synthesised in the interest of defining the core problems. The **Step 3 (Ideate)** is represented by the idea's generation and development process. This is where team members are challenged to think outside the box to identify innovative solutions to the problem statement defined in the previous stage.

Within the **Step 4 (Prototype)** and **Step 5 (Test)**, several cost effective and downscaled versions of the products/services are created, so teams can tackle and examine the solutions resulted from the Ideate step. Each one of these solutions are then conducted within the prototypes and consequently examined to decide if they are accepted, refined, upgraded, or abandoned taking into account the user's experiences. In addition to the traditional DT strategy, a series of customer validation techniques derived from the LS were also conducted to find an optimal solution for the problems detected in previous stages. Finally, the problem statements were revisited, and then ensured that the identified solutions met the user's needs and consequently eliminated their frustrations. To achieve this goal, the authors suggested the application of the BML cycle from LS to iteratively test and redefine the given problem solutions till the market fit is reached.

Something great about the DT and LS model is that it can rationalize in a systematic way how to understand and undertake any problem-solving project. However, it is important to mention for its non-linearity and iterative nature. Which means that, the previous five constituting phases do not necessarily follow any specific sequence of steps and could often show up in parallel and be replicated iteratively. In addition to the proposed model, the authors brought together a set of tools and techniques to facilitate and provide guidance to practitioners when applying each one of the methodological steps. The majority of these tools and techniques were taken from the various authors introduced from prior literature research and then clustered according to each designing step, as portrayed in Figure 3.

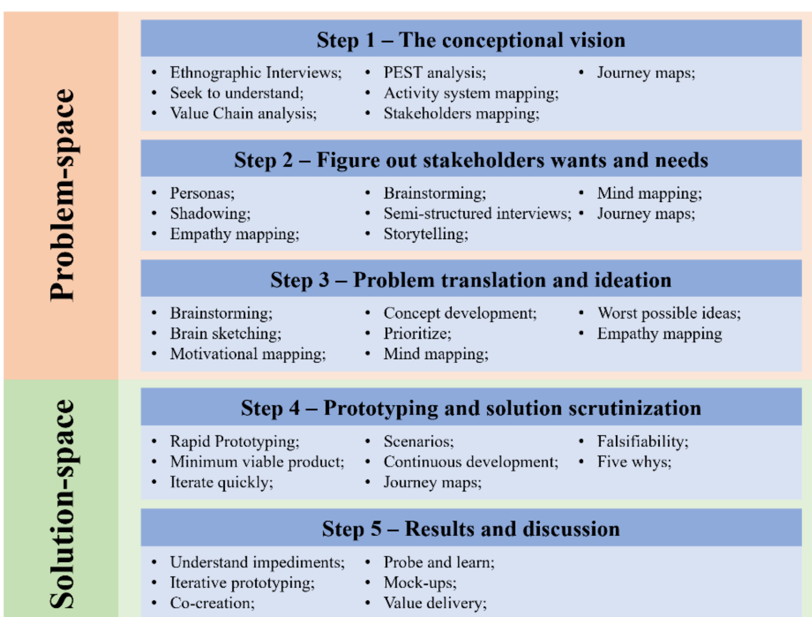

Figure 3. Suggested tools and techniques to apply in each step of the DT and LS model

4. Case Study

The proposed methodology application was explored on an empirical case study based on the Smart Waste Collection System (SWCS), developed by the authors in a multinational consulting company that is currently in charge of a smart city initiative in a European municipality. This application made use of the before mentioned methodological steps as well as some tools and practices presented in the methodology (*i.e.* journey and stakeholders' maps, value chain analysis, etc.) in order to filter and figure out the most relevant information between the massive amount of data gathered.

4.1 Step 1 – The conceptional vision

The initial step of the methodology is intended to give an overall picture of the specific case study environment, being divided in two main topics: a comprehensive vision of the industry; and a contextualization of the specific case study environment.

In the first topic a temporal and conceptual overview was made regarding the waste management industry along the last five decades, together with the current trends and the key factors that contributed to its evolution and consequent transformation. Afterwards, the focus was directed to the municipal solid waste (MSW), as the waste exclusively generated by households, due to its representativeness in the complexity and huge facing challenges by SC. In this latter, the particularities of MSW value chain were explored from country-to-country just as from higher to lower-income countries, followed by the key policies and legislation in the European Union and especially the PERSU2020 objectives to be accomplished by the municipality in study. Subsequently, the waste collection systems (WCS) properties were emphasized as crucial to provide cities and citizens a sustainable waste management process, along with maintaining public health and reducing the environmental pollution.

In the second topic, the authors meant to be company-specific, supporting his research on the route optimization process and operational efficiency in regards to the WCS of an innovative SC project in an European country, conceived and operated by the organization in study, in partnership with the local municipality that is in charge of the WM process. Hence, the latter started by introducing the current WCS characteristics of the municipality and giving a technical description of its components and main features. Moreover, the municipality's WCS environment was then explored, representing both its key stakeholders and their influence/interest in the system in study, as represented on Figure 4. Additionally, an exhaustive description regarding the definition of WCS routines was carried out together with the MSW journey in the municipality's ecosystem, equally depicting the waste collection routes and operational performances. At last, the specific smart city context was presented in order to understand the current stage of development and finally the organizational background was framed, portraying the overall in-site hierarchy and relationship with the municipality's staff.

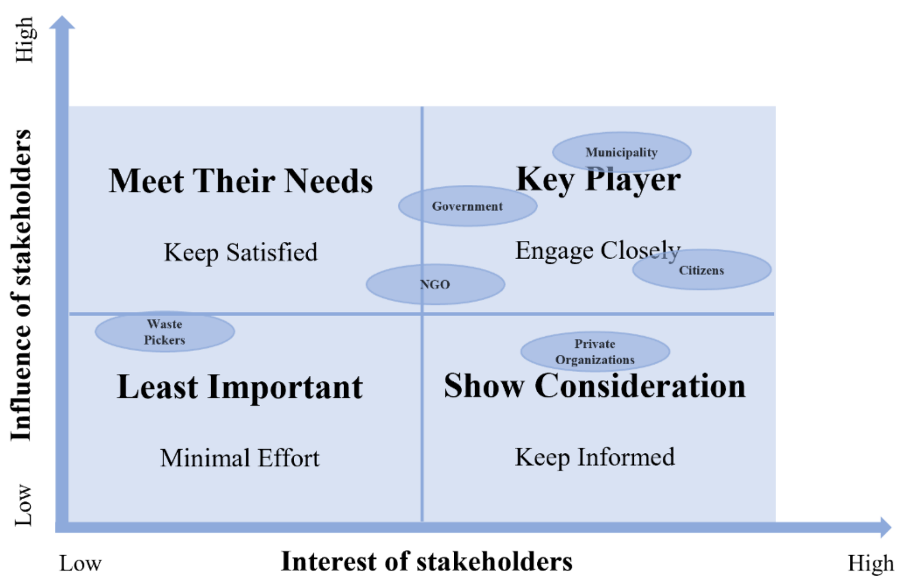

Figure 4. WCS Influence/Interest stakeholders' matrix

4.2 Step 2 – Figure out stakeholders wants and needs

Once defined the WM industry and in particular the WCS environment (comprising both the components and stakeholders involved in the process), together with an overall view of the specific SC initiative developed by the organization in study, one could now empathize with the stakeholders on whom the Step 1 was based. In this stage, the objective was to enhance the problem-space understanding by developing a sense of empathy towards the stakeholders comprised in the system, gaining insights about their needs, motivations, thoughts and emotions. Hence, to gather these insights concerning WCS framework along with different scopes of improvement, a collection of methods and tools were employed while observing the stakeholder's in their natural environment (*i.e.* while performing their jobs) passively, or engaging with them in interviews.

In order to get an initial picture of the various processes adopted in the WCS preparation and forecast as well as during its real-time monitorization, a shadowing process was undertaken in the municipality's integrated control and command centre (ICCC), wherein the control room operators were closely observed throughout their "normal" activities. This ranged from 3 to 6 hours within different time frames and in different days of the week (totalizing 20 hours), where the researchers made use of an observation sheet to collect the numerous process points to guide the shadow observation. At the end of the shadowing process, the latter got the chance to spend some time observing one of the operational and technical directors' routines, which allowed him to pose some questions regarding the WCS control room operators and the waste pickers interactions, together with some data related to the collection routines stages and operational performances.

Upon the shadowing process, the researchers conducted a series of semi-structured interviews comprehending the WCS main stakeholders. This enabled the latter balancing his current understanding about the WCS processes with an "open free form" discussion in order to get new insights that could not be anticipated. These interviews were undertaken individually and in-person and comprised both internal and external stakeholders of the WCS process, as follows in Figure 5. As a result, a total of 14 interviews were made by the authors, each one of them in Figure 5 represented by a circle, with a duration of approximately thirty minutes to one hour. Each interview was conducted in the natural environment of the stakeholder and followed a specific set of protocols or scripts to match each type of interviewee. This process allowed the various interviewees to think towards a specific flow in the interest of achieving creativity or discover innovative solutions for the problems.

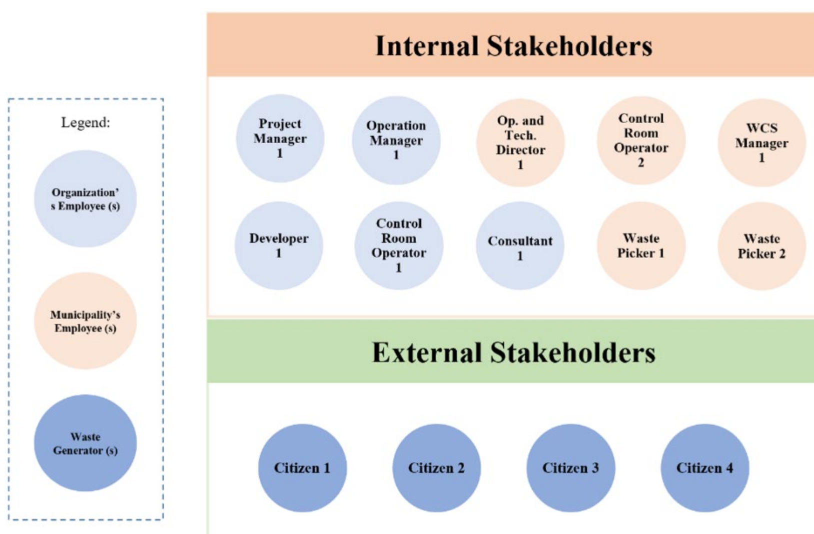

Figure 5. Number of interviews by WCS internal and external stakeholders

Subsequently, the authors took inspiration from the various notes and drafts collected during the semi-structured interviews and initiated the creation of the mind maps. In the present study, a total of 14 mind maps were created, each corresponding to a specific interviewee. This method allowed to structure all the ideas, loose words and misunderstood connections into a visually organized diagram, enabling the discovery of new patterns and insights about the WCS design. In essence, all these ideas and drawings were organized in a visually brain-friendly method, breaking down complex situations into smaller parts. In parallel with the interviews, the researchers also invited eight individuals with different profiles and service groups to share their stories regarding the waste collection system in study, with the main goal of developing a deep and emotional understanding of their numerous motivations and needs. In order to avoid preconceptions and to get a wider perspective of the collected stories, the researchers comprehended both service providers and service users of the WCS. Aside from choosing individuals from different service groups, other key requirements considered to broaden the stories profiles were age category, intimacy with the WCS, awareness of the waste collection stages, respect for collection times and types, amongst others.

Afterwards the implementation of the previous tools (*i.e.* semi-structured interviews, mind maps and storytelling), the researchers had a large number of scattered information regarding the various stakeholders' understandings and perspectives in relation to the WCS in study, for which he needed to summarize and organize in a single format. For that purpose, the personas tool was used once it allowed the creation of a fictional character relying on a synthesis of what it was captured and learned about the real stakeholders (during the interviews) along with the mutual ideas and perspectives that many of them shared in common. Thus, for each persona, the authors associated a specific stakeholder's category, determined as essential to the WCS routes and operational performance, comprising both their behaviours, overall opinions, major goals and concerns. While the majority of stakeholder's categories were comprehended into one persona (one stakeholder category to one persona), there were two exceptional cases wherein the stakeholder's categories were respectively clustered or separated. Hence, the 14 interviews made previously resulted in a total of 8 personas, wherein one represents the external stakeholders and the remaining seven the internal stakeholders. Both the personas profile template as well as the present description of the WCS stakeholders' personas are represented as follows in Figure 6.

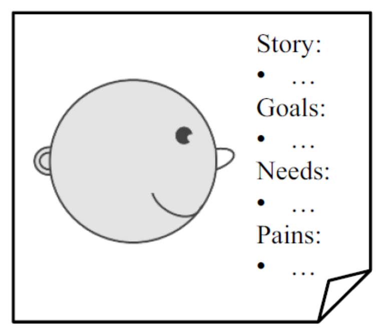

Figure 6. WCS stakeholders' personas (on the left) and personas template (on the right) – adapted from: Romero & Molina (2015)

4.3 Step 3 – Problem translation and ideation

The present step of the methodology is represented by the creation of a collaborative environment to debate and iterate over the different insights observed and perceived by the researchers of the problem-space, together with an initial exploration of the solution space. This involved an iterative process wherein the various WCS internal and external stakeholders were challenged to develop and make clear the problem definition, and, subsequently, to conceptualize innovative solutions considering the given problem.

On a first view, the researchers started by examining the different perspectives and insights collected during the empathy phase, with the purpose of digging deeper any irrelevant points or even figure out more deepen and meaningful data concerning the various WCS processes and activities. As a result, the latter gave one more look and reanalysed all the previously made drafts and sketches from the semi-structured interviews as well as the created mind maps and personas, in order to create empathy maps. Despite empathy maps are usually applied to further design the user personas, in the specific case, the authors used it in other way around, since it is a great tool to synthesize and organize the different perspectives and other qualitative data from the research phase, and simultaneously, to draw out additional unexpected insights. However, one should mention that this tool does not represent an alternative to the persona's tool but indeed an addition, since, while personas tend to cover more the demographic side of the interviewees, the empathy maps are more focused on the behavioural sides, underlying the feelings and the "why" behind user actions, decisions and choices. Hence, the researchers developed a total of 14 empathy maps, in which, as a central topic, were used an extension of each one the personas represented before in Figure 6. As such, the following Figure 7 illustrates one of the fourteen personas empathy maps made during this process, more specifically the waste picker one.

Figure 7. WCS waste picker persona empathy map

After the creation of the persona's empathy maps and the consequent exploration of deeper perspectives and connections regarding the specific problem space comprehension, the authors came to a decision and understood that there were already enough pains and needs specified across the different collection processes. As a consequence, the latter had to figure out a way to filter them and identify which were the most critical ones (pains and needs) for the WCS in study, so that it could subsequently present and discuss in an efficient way with a group of experts in that matter. For that reason, the researchers first transcribed all the 14 personas empathy maps pains and needs into an Excel sheet and subsequently applied a multi-criteria prioritization. In essence, this tool consisted in generating a variety of appropriate criteria's that converted the relevance of a given pain and need, and consequently give to each one of them a corresponding score for each criterion.

In that process, the authors managed to prioritize the top four key concerns, which were further taken into consideration on the succeeding demonstration and discussion with the group of experts. This group of experts brought together both project and operational managers, developers, consultants and engineers from different operational and back-office teams with many years of experience (ranging from 2 to 30 years) not only when dealing with waste collection systems, but also with this relatively new concept of SCs. The meeting began with the presentation of the general picture of the current WCS environment, followed by the current SC context and the organizational framework, subsequently succeeded by the introduction and discussion of the top four concerns prioritized initially. During this phase, various inputs were given by the different participants, several of them with the goal of enhancing and fine-tuning the researcher's understanding, and the rest of them to better investigate and deepen the key concern's comprehension and awareness, so that later it would be possible to reach an agreement on which one of them would be the most desirable and innovative opportunity to explore. As a consequence, it was decided on one most desirable and innovative opportunity to be investigated, and which specifically represented the opportunity that would be further developed on the solution exploration step of the methodology:

- "Need for more efficient and dynamic collection routes"

4.4 Step 4 – Prototyping and solution scrutinization

At the present step, the WCS major concern/opportunity had been identified by the group of experts and which it will be further explored and scrutinized along this step. The identified opportunity was associated with one of the most crucial processes of the WCS, if not the most crucial one. This latter is specifically related to the collection routes efficiency that are transversal to all the WCS activities and which the researchers could leverage thanks to the IoT and digital technology at his disposal in the current SC project, not to forget that it was one of the author's key research purposes to investigate. Down this step, the authors implemented some techniques in order to get deeper into the identified opportunity and put into perspective various solutions possibilities according to their suitability when it comes to the overall paper's objective of enhancing WCS routes, and feasibility in regards to time, data and available technology to further explore the designated solution.

On a first stage, the researchers started to further investigate the previously identified opportunity (during the co-ideation phase) by applying a fishbone diagram, also known as Ishikawa diagram. This tool, often used in quality management, is slightly different from other visualization tools such as the mind maps or empathy maps, since it displays multiple causes that are ordered logically in a visual manner, and they are used to solve problems instead of helping to capture free flow ideas during a brainstorming session and subsequently develop an idea (as in the case of mind maps). On the other hand, fishbone diagrams are a great way to develop a clear definition of the problem, once they help to identify the central reason that caused the problem and make up with a way to solve it rather than handling its symptoms. Hence, the previously defined opportunity was converted into a more tangible and precise solution to be further investigated:

- "Provision of containers real-time data to develop more efficient and dynamic collection routes"

In essence, real-time monitorization of waste containers filling levels would allow collection teams to effectively pick-up the containers that only had a certain percentage of waste in it, *i.e.* avoiding unnecessary collections. This would be possible thanks to the installation of IoT sensors in parallel with Information and Communication Technology (ICT) that would provide the accurate quantity of waste gathered in each container, allowing collection teams to adapt their routes in accordance to a certain percentage of filling levels. As such, in the following sections of the present paper the authors focused their efforts in exploring the solution space by developing a prototype of a smart waste collection system (SWCS) by combining IoT-related and ICT from the smart city in development with up-to-date waste management routines in the view of finding optimal collection routes for the municipality's collection vehicles.

Hence, in a first part, the researchers gathered a meeting with the organization's group of experts, that had a long experience in WCS related IT projects, with the objective of rapid prototyping the various functional and non-functional requirements that should be integrated in the system. As a result, a total of 20 requirements have been successfully identified and consecutively divided into 7 functional and 13 non-functional requirements. In essence, the main difference between these latter is that functional requirements describe what the system should do (*e.g.* measure the quantity of waste, optimize collection routes, etc.), while non-functional requirements describe how the system works (*e.g.* scalability, usability, availability, etc.). Once agreed the key system requirements, the authors carried out a research in the view of identifying all the necessary components to meet the previously defined requirements. This involved two different types of research: a first one regarded the investigation of public materials (*e.g.* papers and journals) and a second one concerned the research of the organization's private materials.

Afterwards the identification of the key system requirements with the group of experts, on a second part, the authors explored how these could be met through the conceptualization and construction of the system modeling. This latter was fundamental, given that it allowed, in an initial approach, to develop numerous models representing not only the system's overall behaviour, but also the involved actors, components and functions that the system was intended to fulfil. For the development of these models, the researchers took advantage of the Unified Modeling Language (UML) notation to build several diagrams (*i.e.* activity, use case, sequence, class and state diagrams) in order to schematically describe the complexity of the system across multiple abstract representations of disciplines and technical domains. On the other hand, one should mention that the design and schematization of the system modeling did not involve a linear process of development but an iterative process instead, which concerned the continuous integration, verification and validation of the evolving prototype and the continuous demonstration of progress to the above-mentioned group of experts. As a result, given the potential of the prototype in terms of optimizing the efficiency of WCS routes, enhancing the performance of waste collection team's and also in terms of low development and deployment costs, it was agreed that the researchers could now move to the implementation phase.

The third and last part of the prototyping phase regards the SWCS implementation *per se*, wherein the authors iterated collaboratively with a group of experts regarding the development of an IoT enabled smart waste collection system (SWCS) prototype for a SC initiative in a European municipality. This latter was subsequently divided in three different stages: the first stage concerned the development of the hardware architecture, more specifically the aggregation of electrical circuits, network communication modules and IoT sensors (*i.e.* ultrasonic sensors and RFID tags); the second stage more focused on the software components that were comprised in the development of a web infrastructure, comprehending a cloud-based server application and a web management platform; and the third stage concerned the development of a mobile application, which was further integrated and connected to the cloud-based server, to be used by collection vehicle's drivers. The proposed SWCS architecture is briefly schematized in Figure 8. Eventually, the development of the SWCS prototype led to a number of tests that were further explored on the next step of the DT and LS methodology (Step 5), wherein the proposed solution was examined and tested to see if it could have a positive effect in attending the previously identified problem on Step 3.

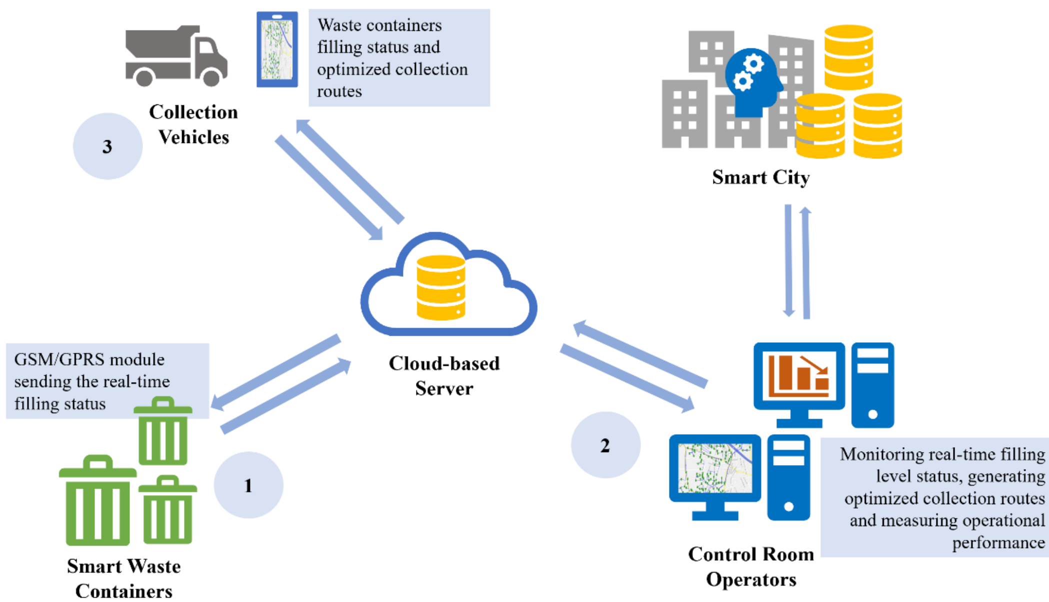

Figure 8. SWCS architecture

4.5 Step 5 – Results and discussion

This step had the purpose to undertake a prove of concept (PoC) of the implemented SWCS solution, conceptualized and developed on the prior Step 4 of the methodology, and which intended to enhance more efficient and dynamic collection routes by providing real-time data from the municipality's waste containers network. As such, the researchers divided this step in three sub-sections. On the first sub-section, the authors explored the municipality's current WCS application scenario so that one could have a base value to further compare with the results estimated in the proposed solution. Hence, in the view of simplifying the validation process of the proposed SWCS prototype, the researchers exclusively focused his efforts in studying and analysing all the integral parts of the waste collection management related to the household production of the mixed type of waste (*i.e.* excluding all the recyclables types of waste), which covered 5470 waste containers unevenly distributed among 16 different collection routes. In this latter, the various characteristics of the municipality's present collection system were examined along with historical data concerning a six month period and then calculated the traditional WCS key performance indicators per month.

Additionally, on the second sub-section, given the huge financial effort involved in developing one prototype to all the waste containers present in the municipality's network, the researchers decided to make a simulation of the SWCS prototype assuming a linear growth in the amount of deposited material in the waste containers and take into account their weekly collection frequency. Afterwards being determined the average number of days to fill up the containers, it was defined a percentage range (*i.e.* between 8% and 28%), wherein between these parameters, a program would periodically simulate the daily filling of all the containers present in the municipality's network by adding a random value (comprehended between that range) to the previous days records. However, when it comes to generating the optimal collection routes according to the waste containers filling status, it was defined in the SWCS web platform that waste containers would only be eligible for collection when this latter were equal to or higher than 70% filled. Subsequently, a comparison was made between the various KPIs obtained from the SWCS simulation and the traditional WCS. Some of the gains obtained through the implementation of the SWCS prototype were:

- Higher number of containers picked up per kilometres made by the collection vehicle teams;
- Reduction in the amount of fuel consumed, leading both to economic and environmental gains;
- Increase of the effective collection time and reduction of the total duration of the collection activity;
- Reduction in the number of collection routines required to make per week and decrease in the amount of vehicles and operational teams needed to provide those routines.

Following the simulation of the proposed SWCS prototype, developed within the municipality's WCS application scenario, the third and last sub-section involved in presenting the developed prototype along with the results obtained from the simulation to both the organization's project manager and the municipality's operational and technical director, as well as discussing new possibilities to further include in future SWCS prototypes. This means that despite the validation of SWCS process was successful, one should still develop additional prototypes to further adapt the proposed solution into the various needs of the municipality WCS. This could involve in returning into the problem-space exploration to iteratively gather new insights and perspectives from the various feedback received, both from the organization in study and the municipality's group of experts, in order to enhance the just made prototype till it reaches the product market fit, as represented in the Lean Startup build-measure-learn cycle contemplated in the methodology. Only then it could be subsequently applied in the municipality ecosystem and incorporated within the SC integrated control and command centre (ICCC).

5. Conclusions

This paper aimed to address the proposal of a hybrid methodology combining Design Thinking (DT) and Lean Startup (ST) to enhance waste collection systems (WCS) in a municipality in Europe that had recently adopted a smart city (SC) initiative. With this in view, it was made a comprehensive literature review about the two different topics considered by the methodology, which were: Design Thinking and Lean Startup. This latter were then tested by carrying out a case study investigation methodology, wherein the authors could analyse it at the same time that was being applied on an empirical application. Throughout the application of the case study, it was demonstrated the ability of merging the Design Thinking and Lean Startup techniques to have an increased knowledge of the WCS context of the present municipality. Moreover, along the empirical application, the researchers developed an initial prototype which allowed the optimization of waste collection routines by leveraging from the real-time data from the smart waste containers as well as to conceive larger possibilities that could add an immense value in terms of routes optimization and also in operational management.

Additionally, prompt fuel and operational savings were represented with an overall estimation about the economic earnings that SWCS prototype could bring to municipality once implemented in the real application scenario, as well as in terms of reducing the emissions of carbon dioxide. In addition, the proposed prototype also allowed to glimpse much more results by continuing the iterative process of exploration and refinement with constant feedback from both the municipality's and the organization's group of experts. Finally, the methodology application was considered very successful, not exclusively as an innovative method to better understand and consequently improve the optimization of waste collection routes, but also with numerous other impacts that could be applied in a widespread of cases. In conclusion, this methodology was considered as entirely viable for a holistic conceptualization of a smart waste collection system which can consider the several external and internal stakeholders perspectives and needs, together with dynamic and efficient tools to help the municipality's daily decision making process.

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Biography

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