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Article

Architecting and Designing Sustainable Smart City Services in Living Lab Environment

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Abstract: In terms of sustainability, cities become smart when they provide intelligent services to the inhabitants using information and communication technologies without threatening the future of the environment, economy or the society. However, the process of developing such sustainable smart services has certain challenges, especially in understanding the real needs of the people living in the city. Inhabitants of the city or the citizens are the key stakeholders in case of smart services in a city. Active involvement of the people throughout the process is a way to design such services. On the other hand, integrating sustainability, for example including environmental data to the smart city services has been found challenging. Therefore, this research discusses an approach on combining environmental data with regular smart city services and to engage city inhabitants in the process, the approach that is adapted from the concept of living lab methodology. Finally, an application has been developed to represent a smart city service following this method.

Keywords: Smart City Services, Sustainability, Living Lab

1. Introduction

It is reported by the UN, that in 2016 around 23 percent of the world's population lived in the cities. The UN also projects that by 2030, 60 percent of global population will live in urban areas [1]. It can be understood that cities are growing in an extensive manner. To scale basic services to the extent of increasing demand the cities have to follow an intelligent method. A city that connects its physical infrastructure, social system and economic framework with IT system to increase the overall intelligence of the city can be referred as a "Smart City". Increasing the Intelligence meaning making better operational choices combining analytics and modelling [2].

The term "**Smart City**" has become one of the attractive topics in the recent era of science. A smart city can be defined from various perspective. In simple words, a city with technological advances that supports citizen in their daily tasks is considered a smart city. However, with the increase in city population, adverse pressure in the form of social, economic and environmental effects can be noticed in the cities [3]. Now, to motivate citizens to be sustainable in a smart city is a challenge along with designing a service that promotes sustainable behavior.

Due to rapid Urbanization, around three-fourth of the total energy consumption and most of the GHG emissions are caused in the cities and that makes the cities a good candidate for sustainable development actions. Though there is a desire to monitor the **sustainability** of cities (or effects of sustainable actions) but the information regarding this phenomenon is quite vague [3]. "Establishing reliable methods for measuring sustainability is currently a major issue, which acts as the driving force in the discussion on sustainable development [3]", the author points that knowledge regarding measuring sustainability needs to develop before establishing a sustainable city. There are many confusions in assessing the sustainability in cities. Designing services to correctly quantify sustainability is essential for distinguishing procedures that are not sustainable, advising engineers about their reliability and assessing their human impact [4].

Citizens are one of the main types of consumers of these smart city services. In this research citizens are coined as inhabitants; people living in the city over a period of time and do not concern with legal rights, for example rights to vote in national elections. Thus, it excludes people visiting the city for a short time. Now, inhabitants of a city are more likely to use the services that they require the most for their essential task, such as mobility or housing. The services that mainly focus on the environmental aspects do well during test cases but loses citizen involvement in the long run. As described in a research, "Human motivation is inherently dynamic; what motivates us to start an action might change while we are performing that action" [5]. There are many data available that is being used by applications to motivate citizens in a smart city. However, if these services could have more attention smart cities could achieve sustainability in a faster pace.

Smart city services are acknowledged to increase the overall living quality of the inhabitants [6]. Smart cities intend to apply information and communication technology (ICT) in many ways such as, to monitor city transportation, water supply, traffic and providing road safety, e-health facilities and these in general would sustain the socio-economic wellbeing of the inhabitants of a city [7]. In case of designing such services, certain user interaction method should be followed. Innovating a new technology or service for the public sector must be developed from a different perspective. Citizen are not only users, they are also an active part of the development process. Citizens are concerned with the advancement of technology thus their requirements and expectation have become appropriate [8]. According to researchers, development in public sectors are becoming complex by time and it requires more than one entity to produce a solution maintaining many layers of complexity [9]. Open innovations involving citizen involvement in the process can be a solution to such complexity. Living labs are special environment created in real life settings, to accommodate open innovations where citizen can actively take part through the lifetime of the project following specific methodologies using special tools and further implemented in the community [10].

1.1 Research Questions

A smart city can be made sustainable in many ways, for example, ICT can be used to reduce power consumption or reduce air pollution. Study shows that using automated sensors in home or office environment to control electronic equipment reduces energy consumption and proper visualization motivates user to be conscious about their usage [11]. This research proposes a way to make environmental data visible to the citizens by integrating the data with traditional smart city services. At the same time, we engage citizens to the sustainable development.

The main research questions that has been addressed through the work, are as follows,

1. How to integrate sustainability into smart city services by following Living Lab methodology?
2. What is the experience of the users in terms of viewing environmental data in case of the service presented in this research?

The first question has been addressed by related works, one of the living lab methodology and describing the process by designing a prototype and developing an application to represent a sustainable smart city service. The second question is solved through online survey by letting a group of people living in the city test the service and answering a list of usability questions.

1.2 Goals and delimitations

In respect to the situation discussed in the previous section, there is a lack of environmental aspect in the regular smart city services specially in the software applications. Therefore, the main motivation of this research is to showcase a design approach to develop smart city services which also has environmental information to facilitate citizen knowledge on sustainability in cities. This paper aims to achieve two goals in the process. At first it follows the selected human involvement methodology to develop a sustainable smart city service, with as much as citizen interactions possible. Next, the developed prototype, in this case which is an online map application is tested for user experience through an online survey.

In case of the technical part of the research, the formulas used to calculate certain values are explained and referenced in detail in the process. The prototype application was independently developed by the authors using open resources and open environmental data following standard application development techniques. The research is conducted focusing on the citizens of greater Helsinki area, where the surveys are conducted on full and part-time students of two popular Universities and very few business owners in the area. Though the process reflects a design process to develop an application for smart city service that provide environmental data alongside regular services, this process can be slightly modified and followed to design different smart city services as well.

2. Related Work

The section is divided in three parts supporting the background knowledge to solve the research questions mentioned earlier. The studies that have been found relating to smart city services, living labs, and sustainability. have mostly defined the topics in different scenarios and stated their advantages. Further, we have reviewed the literature that relates sustainability to smart city services and living lab as an environment supporting to develop that relation.

2.1 Smart City Services

Development of Urban life in terms of quality, improved services and environmental sustainability can be termed as "Smart City". Many definitions are built around the concept of Information and Technology, which is considered a key element in smart cities [12]. In this case, smart city cannot be confused with digital city where written documents are transformed to digital form, book keeping moved to computer database. Here, information is not only stored from citizens but there are sensors automatically collecting real time data, systems that analyze these data and actuators sending out signals to keep the city services active round the clock [13]. In terms of providing services a city can be considered as an organization, the customers are the citizens. Citizens are the stakeholders as well as active part of the development process. The services are built to serve the citizens, so they should be built around them. Since, citizen demands for smarter service, more information and forecasting cities are bound to provide smart services. These services provide solution for smart industry, smart education systems, smart governance or smart industry. According to the researchers, cities are considered smart when the services are versatile, interconnected, adaptive, self-sufficient and repairs themselves [14]. Smart city is vast area and there many dimensions to the provides services [15],

Smart City Governance: In case of smart governance, citizens are active participators in decision making and government is transparent in its actions. Citizens have better knowledge of the functionalities in the city due to technology, which results in a well-connected governance system.

Smart Mobility: Mobility services are combined with technology to provide actual information on availability of transportations and decreases redundant rotation of public transport by following citizen usage patterns.

Smart Environment: By monitoring environmental change, smart services can provide real time information on pollution growing in the cities. Governments and citizens can be made aware of the adverse effect, to change their behavior towards utility services such as electricity, water and gas.

Smart Living: Citizens are offered healthy and safe living environment as well as personal medical assistance, efficient health care plans and remote medical services to ensure their personal safety.

Figure 1 presents a list of example application areas in a smart city [14]. For example, in smart buildings heating can be controlled according to the presence of inhabitants, sensors can monitor the busy hours and keep the building intelligently heated. Autonomous control ensures maximum use of resources by distributing them across different areas. On the other hand, with proper data from public services, developers can create efficient applications for citizens to get accurate schedules for buses or trains.

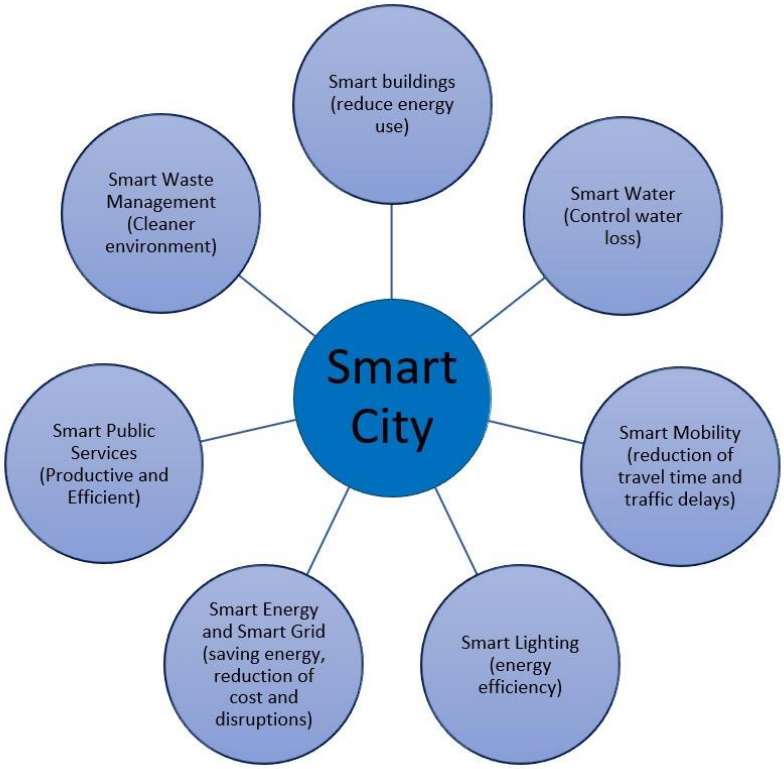

Figure 1. Different application areas in a Smart City [14].

Technological solutions lie at the core of smart city. However, in every modern conceptualization, insightfulness goes past the sort of knowledge that can be decreased to the utilization of new ICTs. This is the reason both social and natural measurements are fundamental components of the keen city idea [16]. The idea behind smart city has grown from local communities where inhabitants, enterprises and governments utilize information technology to fortify and remodel the communal administration level to provide jobs, equality and enhance the nature of social life [17]. Smart cities should not be realized as a service, product or innovation as it is a combination of beliefs to make new changes in urban systems and policies. It provides a framework for public sectors to promote the city services in an intelligent manner [18].

Applications in smart city are not simple to design and develop. These applications must make a connection between the city resources and the citizens. Transforming physical systems to online services is a complex task. In many cases, the applications are developed in private sector and provided to the public in addition to traditional services with very low or free of cost. The services in smart city needs to be user friendly, adaptive to the city structure and sustainable for the environment. Smart city services can be developed in different forms, for example it can be web application, mobile application or a simple web service. The online services are researched and developed using data and ICT to improve the quality and standards of urban lifestyle [19]. It must provide consistent and real time information to support the services in the city and gain the trust among the citizens. Developing and maintaining the services are costly, therefore proper functionality of these services ensures revenues in future. City governance is benefited by the services, as they can acquire actual data on citizen actions and behaviors, so that appropriate measures could be taken to handle complications long before they are generated [14].

2.2 Living Lab Methodology

There are many ways that invoke innovation among mankind. Living labs are one of a kind modern solution to offer an environment to harness innovation. It is an environment, a process to

foster ideas and converting them into solutions. In other terms, it is considered as an open space to discuss and nurture ideas. This open space of innovation is a common conception in the private offices and institutions [20]. As of late, government associations have begun to receive open innovation ways to deal with to give an extra door to development, that enables residents to propose answers for administration issues in an open space [21].

Open advancement is, in this way, about welcoming issue solvers help rehash items, benefits, or even plans of action that may add to the survival of the association [20, 22]. Living lab process, in a way provides such arrangement for open innovation. Two thoughts that motivates Living labs are, firstly, customers as co-makers of advancement results on break even with grounds with whatever is left of member and secondly testing in actual environmental arrangements [8].

There are mainly three pillars to living labs, which is also known as the triangle framework. The pillars are Living lab environment, Living lab approach and Innovation outcome. The living lab environment can be described as the technical infrastructure, real-life context, community, scale, lifespan, level of openness and the ecosystem approach. On the other hand, in the living lab approach, the main concerns are evaluation, context research, co-creation and role of the user. In this case, users should have the ability to provide positive or negative review while interacting with developers and researchers through surveys or vocal interviews. Context of the user is also an influential element in such participatory methods. User roles should also be defined in the process, they are possible roles to be informant, tester, contributor or co-creator. The innovation outcome, which is the 3rd pillar, evaluate the success of living labs [23]. It helps to identify the best approaches and the outcome is affected by the strategy, passion, knowledge, resources and the living lab partners [24].

The research in this paper solely gives priority to select an approach inspired by living lab methods to innovate sustainable smart city services with the inhabitants of a city as an informant and tester. In general, living labs have concentrated on supporting organizations and making an environment of development that advantages both privately owned businesses and open associations. Be that as it may, recently, according to them, citizens can also be considered for open innovation [25]. In terms of other researchers, “the experiments that these spaces facilitate open two symmetrical opportunities. One is the possibility for bottom-up social innovations to move faster in their trajectory from the first ‘heroic’ stage (when social inventions are still prototypes) to the following stages when more mature enterprises are created and, if necessary, when enabling products and services are conceived and enhanced” [26].

The open innovation methodology or more specifically the living lab methodology can be utilized in case of designing smart city services. The success of smart cities depends widely on the involvement of inhabitants in the city. In terms of Eriksson, Niitamo, and Kulkki the idea of living lab as a “user-centric research methodology for sensing, prototyping, validating and refining complex solutions in multiple and evolving real life contexts” [27], therefore it establishes a good ground on the idea of implementing living lab methodology in designing smart city services. In the end, it can be understood that Living lab works as an idea that can be actualized into a process, a methodology, a framework or even a space, which relies on the nature of the requirement [28, 29, 30].

2.3 Sustainability in Smart Cities

According to the Brundtland report from the United Nations (UN), “Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs”. The definition of sustainable development does not entail the progress of mankind by setting certain rules, however it promotes development in a steady pace, in order to let environment and technology be mature enough to mitigate the effects of human activities. Developing in a sustainable manner is often challenging for countries, those are in a poor financial state, considering it is costly to maintain continuous growth and ensuring natural safety. In this state, sustainable behavior is expected upon the rich communities to provide an example, to set a strategy for others to follow, by investing more

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capital and technology in overall development to maintain use of natural resources for sustainable development. Therefore, achieving sustainability is a long term and in many cases exhausting procedure. It is a process of change, where resources, investments, trend of technology and governance is continuously exploited to keep harmony between the present needs and future aspirations [31]. Smart cities are often considered as deployer of enhanced quality of life by enabling advanced technologies through decreasing disruption to natural space. Inclining to that idea, researchers suggest that smart cities will use data and IT, to "provide more efficient services to citizens, to monitor and optimize existing infrastructure, to increase collaboration amongst different economic actors and to encourage innovative business models in both private and public sectors" [8].

Smart cities are a key element in sustainable development, sustainability in cities are equal to achieve sustainable development goals. In the previous section, many dimensions in smart cities has been discussed. Sustainability could be achieved in each dimension of a smart city. Consolidating supportable advancement and urbanization issues, the region of reasonable urban areas has happened to enthusiasm for look into, training, strategy making and organizations – an intrigue that has been showed in all parts of society. In the scholarly world it can be seen in journal, college instruction and projects particularly dedicated to tending to reasonable urban improvement. In people in general division of approach making and arranging, the apparent requirement for maintain capable urban improvement can be found in worldwide discussions, sanctions and associations, in national projects and focuses, and also in neighborhood far reaching designs and natural projects [32]. Sustainable development has also been defined by researchers as "achieving a balance between the development of the urban areas and protection of the environment with an eye to equity in income, employment, shelter, basic services, social infrastructure and transportation in the urban areas" [33]. Moreover, alongside sustainable development, researcher have stated cities to be smart "if its conditions of production do not destroy over time the conditions of its reproduction" [34].

The quick paced urbanization has made urban communities represent over 75% of the worldwide vitality utilization and 80% of the aggregate ozone harming substance (GHG) emanations; awesome arrangement of general worldwide asset utilization occurs in the urban communities. The part of urban communities in supportable improvement has picked up noticeable quality, and the idea of practical urban areas has gotten noteworthy political force worldwide as the focal concentration for driving overall maintainability [3].

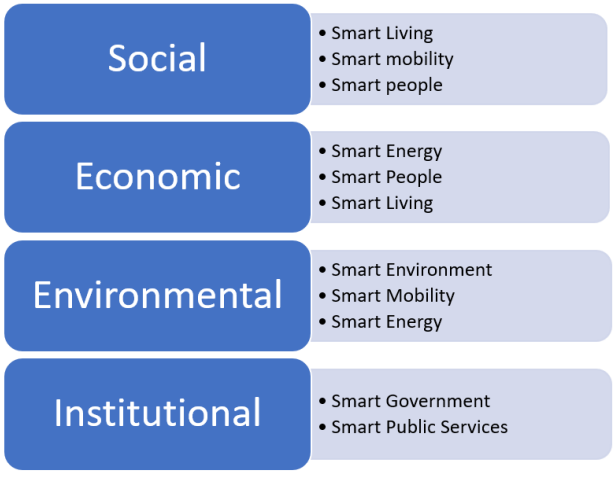

Figure 2. Dimensions of sustainability versus areas in Smart city [3].

Although in most cases sustainability is described in terms of the environment, but there are two or some may three other dimensions of sustainability as well. The areas of smart city are also diverse; thus, they should be properly mapped with the appropriate dimension of sustainability. In a paper the traditional dimension of sustainability is modified to meet the challenges of smart city into

four areas [3]. In the figure 2, it can be noticed that along with Social, Economic and Environmental, the researchers have proposed a fourth area naming it Institutional and it can be seen that same areas of smart city have relation to different dimension of sustainability. For example, smart living has influence in developing social life as well as it has effect on economic factors of sustainability as smart building helps reduce energy costs.

Integrating sustainability in smart cities through ICT has been main agenda for many smart communities. It has been indicated in studies that applications and services developed by NSA are created following the instructions from experts rather including all parties involving in a smart city, thus shifting the goal of the applications to a different level. On the other hand, citizen centric systems can successfully measure social behavior, personal satisfaction, happiness of local area and communal satisfactory impression [35, 36]. In words of other researchers, "the label "smart city" should refer to the capacity of clever people to generate clever solutions to urban problems" [37]. It can be realized that to ICT enabled smart city services are important for sustainability and it is equally necessary to design these services.

Previously, different standards were followed to develop individual components in a system of smart city, for example smart meters, smart grids, smart living and many other. Recently, the strategies to develop smart city services has changed horizontally, following unified standards for accessibility, environment monitoring and others. However, in the unified system, standards are more of a requirement than a conventional method, it additionally provides more usability and reduces unnecessary costs of cross platform problem solution development [38]. Inclining to this strategy researchers also define cities as smart, "when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" [39]. Generally, it can be abridged that there are two standards in the present smart city discourse: 1) the ICT and innovation centered approach and 2) the general population arranged approach. It is called a measurement of shrewd urban communities going from methodologies that objective the productivity and mechanical progression of the city's hard foundations (i.e. transport, water, squander, vitality) to those concentrating on the delicate framework and individuals. Other illustrations used to classify smart city sees are top-down versus base up activities and supply versus request driven methodologies [40].

3. Engaging citizens in designing smart city services

A service cannot be defined as a physical object, as it cannot be touched or smelled. It may be supplementary to a physical object, about its performance or activity. The presence of the service can be identified online, it provides and gathers information [41]. This research focuses on presenting a use case of designing web application, named "Green Commute" that provides data related to sustainability along with regular services in a smart city. As explained earlier, the smart city context is vast enough that it is difficult to represent in a single application, thus only the context of commuting in the city has been analyzed in this research. In case of, innovating an application in a smart city, citizen involvement is a key requirement. In such context, innovating services is a challenge and involving users along the process makes it precarious. Therefore, a modified version of user centric method is used in this research, which is presented in Figure 3. It is called the Form IT model, which is an iterative process consisting three main cycles. In this process, user preferences are evaluated in each step to ensure usability of the innovation. The design process engages users from the preliminary stages of planning to understand their requirements and maintain the correlation between usability and features of the application [41].

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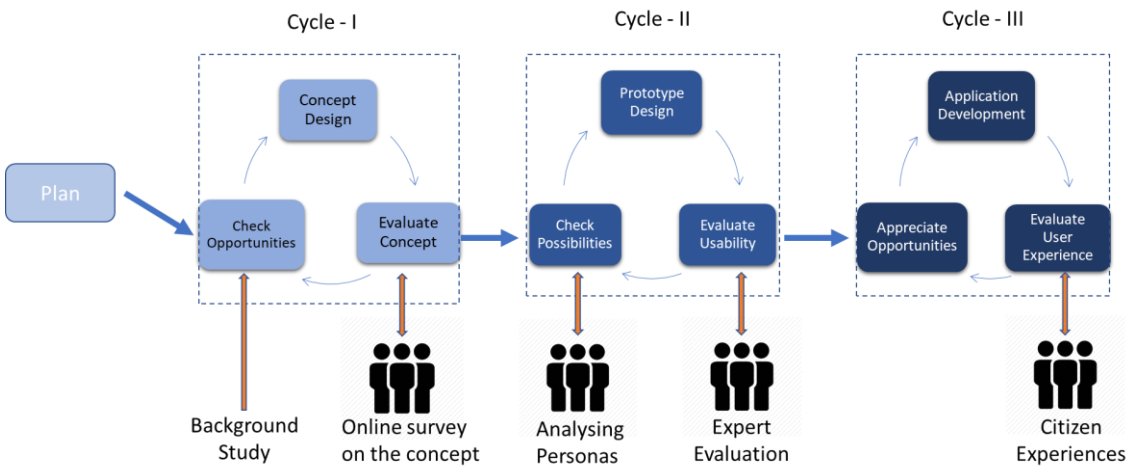

Figure 3. Diagram of the process (Adapted from the Form IT Model) [41].

3.1 Cycle-1

At this cycle ground knowledge is gathered and a concept is constructed on that knowledge, and later on evaluated through users, in this case the people living in a city. There are three phases in the first cycle.

3.1.1 Check Opportunities

In this phase, information is gathered through different resources, such as scientific research paper, report from national organization and government and university websites. As discussion in the earlier sections, a smart city has many application areas and for the research only one area was chosen to demonstrate the approach. The topic in this case was emission due to passenger vehicles in the city. It was found that in 2015 road transport was the cause of 70% carbon emission, among which almost 45% was caused by passenger cars [42]. In recent years, cities have become a major consumer of energy and resources, making it one of largest emitter of greenhouse gases (GHGs). Among the main six elements of GHGs, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) has the adverse effect on the environment. Early actions to reduce these gas emissions may save in 5%of global gross domestic product (GDP) and if 1% GDP is spent in proper manner, may limit the temperature rise below 2◦C [43]. Among the GHGs CH4 has more adverse effect on the environment but CO2 is found in much larger quantity in our surroundings. Thus, the focus leads to reducing CO2, more specifically carbon which is then addressed as carbon footprint [44]. For many years carbon foot printing has been used as a life cycle impact for global warming [45]. In this case carbon footprint is considered as a potential indicator to global warming. Researchers Wiedmann and Minx, has explained carbon footprint as the total amount of CO2 emissions caused by collective action over the life cycle of a product directly or indirectly [46].

In later studies, it has been suggested that GHGs other than CO2 should be included in the calculation of carbon footprint. A dispute on direct and indirect emission is identified in the process of calculating footprint, thus making the calculation complex. The carbon emitted from burning fossil fuel such as gasoline is counted as direct emission. Contrary to that, electric cookers using electricity produced through burning coal is considered as indirect or embodied emission [43]. The term “Carbon footprint” plays an important role in understanding the individual contribution to carbon emission. Carbon footprint also provides a quantified expression to people, who are not aware of the GHG emissions. Importance of can be identified in various sectors. Due to the quantified values of carbon emission, governments can organize their rules on carbon emission taxes, individuals can understand the effect by measuring the impact of their daily usage of energy products. It is also helpful for researchers to evaluate certain decision in terms of their environmental impact, for example Piecyk and McKinnon have identified fuel consumption and projection in road freight transport in Britain forecast, which is 1.93*107 ton of CO2

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business-as-usual forecast for 2020 [47]. The measurements lead to a better understanding of GHG emission and builds an awareness among the people. However, the various choices of carbon footprint calculators leave the users confused on the results thus leaving the benefits of the service it provides. Along with this information, many forms of open data sources were found that provides information relating to the environment, for example, air quality data, carbon footprint data and weather data. The table below lists some of the open data resources related to the environment,

Table 1. List of open data services for environmental monitoring

No	Name	Services	Coverage
1.	Air Quality	Real time air quality of a city, by providing values of CO2, N2O, SO2, O3.	Worldwide
2.	Lake & Sea Wiki	Finnish Lake and Sea monitoring	Finland
3.	Helsinki Region Infoshare	Air quality, Noise pollution, GHGs Emission	Helsinki, Espoo and Vantaa in Finland
4.	Open Weather Map	Rain, heat forecast	Worldwide
5.	yr	UV, pollen and snow forecast, forest fire.	Worldwide
6.	Keli Forcea	Snow condition in the Highways	Finland
7.	European Environment Agency	CO_2 Emission, Losses due to climate change, Air pollutants from transport	Europe

In addition to the environmental data, many services and APIs were found relating to Carbon footprint calculation and transportation in smart cities.

Table 2. List of Smart City application or Services

No	Application/Service Name	Services	Coverage
1.	HSL	Provides transportation information, ticketing service in Helsinki	Helsinki Region, Finland
2.	SL	Provides transportation information, ticketing service in Stockholm	Stockholm, Sweden
3.	Brighter Planet	Carbon and energy impact quantification in the cloud	Open
4.	Carbon Benchmark Api	The administration gives assessments of normal generation of CO2 and GHGs as a pointer of run of the mill carbon impressions for different exercises.	Open
5.	ParkRight App	Service to find free parking spaces	London, UK

In the table listed above only a few could be presented but there exists a larger number of applications or services. Though the number is noticeable, but none of these applications have direct relation to presenting the impacts on environment. Transport services available in many European

cities are smart in terms of providing best travel route, proper timing, vehicle monitoring and ticketing facility. The applications do not provide carbon footprint calculation in terms of different transport, therefore concerned users tend to move towards separate applications or services to calculate themselves. Unfortunately, the missing relation between the regular smart city services and environmental services causes less use of these services or applications. In addition, researchers added that there is a lack of awareness of the smart services that promote sustainability in a city [48]. Finally, in this phase it can be perceived that there is a divergence in peoples conscious on sustainable services in a city and they do not feel the necessity to use additional service to achieve sustainability.

3.1.2 Concept Design

The learnings from the previous stage are considered while designing the concept of the smart city service shown in the Figure 4. It was understood in the earlier stage that there exists a good number of smart applications and good number of environmental services. However, a relation between these two types of services is very important in recent times for them to be successful in user involvement. The concept was based on three ideas, the available data source, integration of these data sources with regular smart city services and finally presentation of these data sources to its users. To explain this concept an example of transport service can be considered, in which case the service or application provides users living in a city with information on local transport, ticketing system and maps of local areas. The application is used by many users regularly.

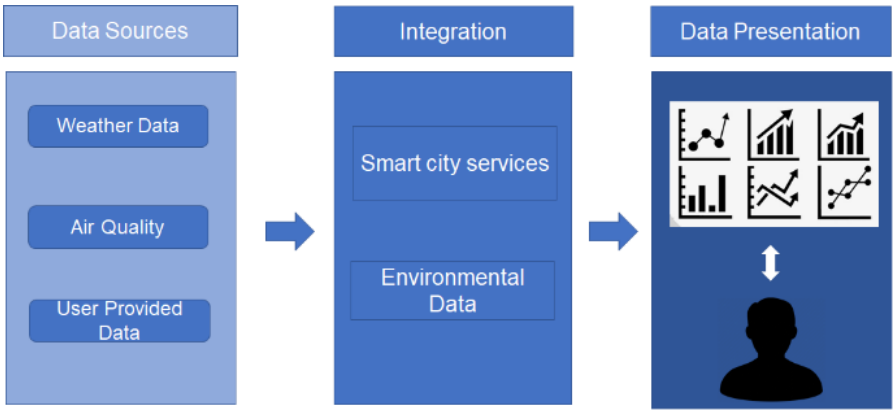

Figure 4. Preliminary concept of the smart city service.

Now, environmental data such as air quality in the surrounding areas, carbon foot printing of different transport choices can be presented in the application. In order to establish a connection with users, there should be an understandable relation with the results provided in the regular smart city service and the environmental data, this is the requirement of integration concept. Later the data should be presented in an interactive format to be receive the attention from the users. The concept promotes the development of sustainable smart city services where environmental data can be tracked with the regular services available in the city.

3.1.3 Evaluate the concept

The living lab methodology includes stakeholders or the prospective users throughout the process to achieve best results. It is valuable to include stakeholders from the beginning of the project, to reach at an aggregated solution which is the main focus of living lab innovation. In such process, people from public and government are invited to participate in the co-creation. Though most of the stakeholders do not feel the professional motivation to take part in such voluntary work, thus a connection should be developed with the people from a problem or an envisioned solution so that the stakeholders find it relevant [49]. The primary concept is therefore evaluated through an online survey to gain maximum knowledge of the people who are expected to use the service. The

survey was conducted in Helsinki, Espoo and Vantaa area through social media and a google form. The questions were constructed to get a view on three points,

a. Knowledge on carbon footprint
b. Apps or services used to Calculate or monitor carbon footprint
c. Peoples view on using an application

The survey was run for 2 weeks and 31 people completed the survey. According to the results, 72% had the concept of carbon footprint but never calculated it. Those who had the knowledge of carbon footprint and calculated it; only 70% of them did it once. Most people also responded that it would be easier to have this environmental information on their regular applications. Among the respondents only one-fourth of them were 35 years or older. The survey was not limited to a student network, rather it was spread out to the public thus response from private jobholders, show owners and government workers were received. It was also noticeable that though Helsinki has a well-connected public transportation system, around two-third of the respondents used personal cars for daily commute.

3.2 Cycle-II

In the second cycle the requirements of the stakeholder, in this case it is people living in Helsinki, Vantaa and Espoo area, are analyzed. The survey outcome from previous cycle is combined at this stage to produce a visual presentation of the service to demonstrate it to the users who are the inhabitants of that certain area. The three phases of this cycle are described further,

3.2.1 Check possibilities

To find the possibilities, the needs of that specific group of users was required. A broad knowledge of the requirement was received through the survey in the previous cycle but to understand the specific requirement a detailed analysis of the personas for the users were required [50]. Phone interviews were conducted with them to get an overall idea about their interests, work and goals. The respondents were from different ages and goals help to define the user requirements in broad manner. For example, one person was a student who has been working in the city part time, on the contrary there is another person who has a well-established business in the city. If the requirements were collected among similar people the service would have gone to one direction, therefore the research involved people from different background which lead to gathering knowledge on the expectation of a variety of people living in the same city. Key requirements that were identified during this stage are listed below,

a. Direction from one place to another
b. Direction for different mode of transport
c. Time and distance for each mode of transport
d. Weather conditions in start and end place
e. Public transportation information
f. Saving a trip for future

3.2.2 Prototype Design

Prototyping is an approach to visualize an application or a software or a service prior to its development. It is used to have an interaction with the system, to understand the point to point navigation of a software system. It is not necessary an exact replica of the final product but an early design schema to feel the end result [51]. Effective prototyping consists of four steps; planning, detailing, designing and results. During the planning of the prototyping, user requirements are verified as it was done during cycle-1. According to researchers, “A digital prototype is almost a digital version of the paper prototype. Except, digital prototypes can range from a series of low-fidelity, narrative click-through screens for quick visualization of a design concept to a high-fidelity interactive portrayal of an evolved design which can be used as a user interface specification” [51]. The Balsamiq prototyping tool was used to develop a mid-level digital prototype.

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The figure-5, represents the prototype in form of a website with basic features to validate the stakeholder requirements. It was designed following the google maps application and along with that three additional information was shown. It followed the idea of integrating environmental data along with results from a map service. Jakob Nielsen has proposed many ideas to design to product to increase usability. In this case 10 Heuristic principle of Jakob Nielsen was followed to design the prototype [52].

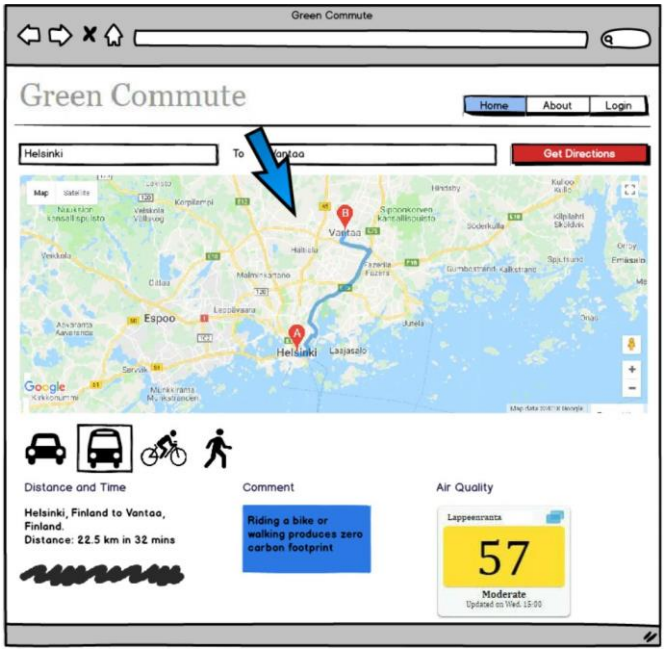

Figure 5. Digital protype of the sustainable smart city service.

3.2.3 Evaluate usability

The digital prototype was further evaluated, and the process is explained in this section. It can help to understand the task flow and context of use. Validation of scenarios, user requirements can be justified to take the design phase to the next level through sequential and interactive task completion using the prototype. The digital prototype was evaluated at this stage following the cognitive walkthrough approach by asking four main question on the prototype [53]. The questions are as follows,

1. Does the action match the user's goal at that point?
2. Will the user see the action is available?
3. Will the user recognize the action is the one they need?
4. Will the user understand the feedback they receive?

This time three usability experts (one Professor, one Post-doctoral researcher and one PhD Student from LUT) judged the prototype, as it was difficult to present it to the people of Helsinki in person. The experts used the presentation method in Balsamiq Tool to understand the scenario. They were not assisted by any of the researcher, the task was evaluated individually by the experts. They were given a set of goals and their task was to achieve these goals using the prototype. It is clear that the prototype is a mid-level digital mock-up, so it actually cannot provide result, but it can reply to pre-configured request given by the users. The task list for the judges are given below,

a. Search for direction between two places.
b. Read the directions
c. Change the mode between different transport choices.
d. Check the amount of carbon footprint for your transport
e. Login/Register

f. Save your journey after login.

The judges each took around 20-25 minutes to analyze the task in detail. They individually noted down the good and bad design choices of the prototype. To summarize, from this phase issues with colors and data presentation were identified and further improved over the cycle.

3.3 Cycle-III

In the last cycle, result from the previous phases are combined and analyzed to develop the final application to represent the sustainable smart city service. In this rotation, the phases are,

3.3.1 Appreciate Opportunities

The motivation for this step by step approach is to understand the needs of the inhabitants of a city and involve their choices throughout the design and development phase. Appreciating the survey results and usability evaluation, it has been understood that the expected user's primary requirement is the existing service, in this case which is the map service and secondary requirement is the environmental data (carbon footprint, air quality, weather) best matched with the primary information.

3.3.2 Application Development

The application to represent the sustainable smart city service was developed at this phase, was given as name of Green Commute App. Most of requirement analysis being completed in the previous stages, this stage focused only on the development. The application was developed by the authors with PHP on the server side, HTML, CSS, JavaScript on the client side and MySQL database to store user data. The AWS Cloud9 IDE (Integrated Development Environment) was used as the development platform.

The air quality (aqicn.org/api/) API provides results according to the request sent from the users. It provides information on pollutants such as PM2.5, PM10, NO2, CO, SO2 and Ozone. It can also provide air quality of a specific area if correct latitude/longitude is given. The API provides air quality forecast for 3 ~ 8 days, along with world ranking and trends. A widget function is also provided where the condition of a area is shown with color codes and a value that notifies users with health hazard if the air quality in a certain range.

The weather API is yr.no. It provides weather forecast, pollen forecast, snow depths, forest fires in a given area. The idea to include weather forecast in transport application is to inform users on the road conditions, so they can choose their mode wisely. For example, they may choose to bike to a place rather using a car if there is a sunny weather.

The google map direction services is used in the application to search for directions. The service takes in two places, and responds with the distance between two points, direction from source to destination. It also provides best possible routes for Cars, Public Transport, Cycle and Walking. JavaScript is used to send request and process the responds from the service.

In order to get distance between two places the google distance matrix service is also used. This service provides the actual distance for different modes of transport between source and destination. The service helps to determine the path covered by the user and the time to cover that distance using that transport.

The calculation of the carbon footprint was done in two methods. In one method average values of carbon emission factor was used, so that users who are not aware of their average mileage can easily get an average value of their carbon footprint. The average CO2 emission factor for passenger cars in Finland in 118 g/km. To calculate total emission, which is considered the carbon footprint is done by the following equation,

Carbon Footprint = Carbon emission factor x Distance covered by the vehicle

On the other hand, the application also has the option to manually provide values in which case the following formula was used[54],

CO2 emissions from a gallon of gasoline = 2,421 grams x 0.99 x (44/12) = 8,788 grams

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= 8.8 kg/gallon
Total Carbon footprint = (Total Distance/Kilometers per Gallon) x 8.8 Kg/gallon

In the Figure 6, the main landing page of the web application can be seen. It resembles the main outlook of a google map, in addition it provides special tabs on top right corner. Users can write in their source and destination to get directions. Later the weather of both source and destination is presented on the right column and best routes are presented on the map with highlighted blue line.

Earlier to getting directions, user can login or register to the system to store their journey and carbon footprint information. They can also set values such as fuel consumption or emission rate of their personal vehicles. The about section clearly describes the methods and functionalities of the system.

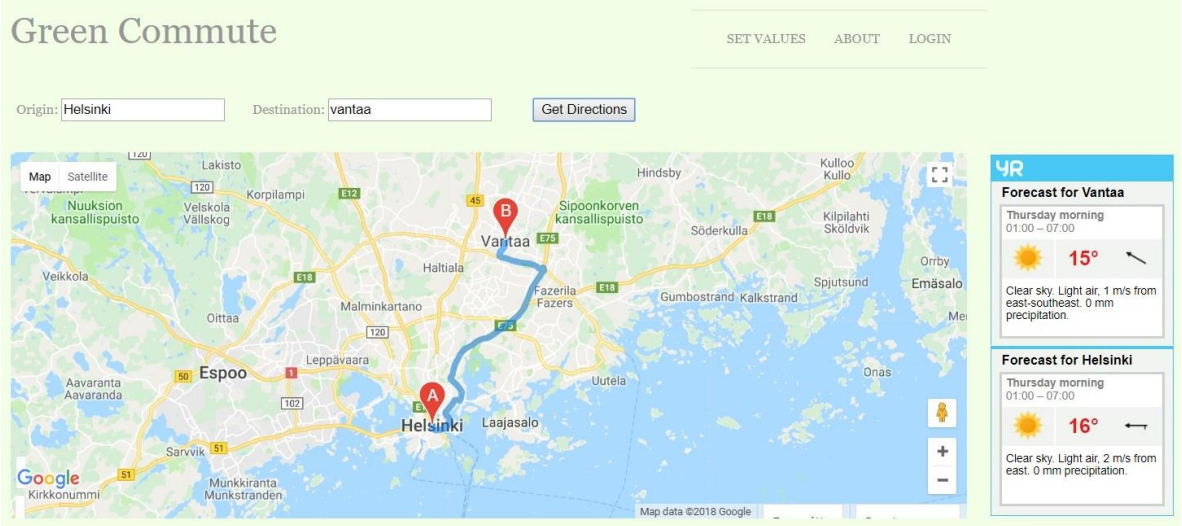

Figure 6. Sustainable Smart City Service in form of the Green Commute App.

The second section of the application is visualized in the figure 7. In this section the details related to the journey is presented. It provides the time and distance of the journey. The air quality widget is also shown to make the users understand the possible health hazards in the area. Clicking on the widget shows quantitative values of air pollutants in that area. A graph is also presented to view the possible air pollutant emitted by the mode of transport chosen by the user. This graph creates a connection with the air quality widget as one shows the current situation and another show the possible addition to the environment. The integration of such data is expected to make people living in the city understand their part in air pollution. The comment sections provide notes to user on their choice of mode to easily realize the environment friendly option to travel on the basis of carbon emission.

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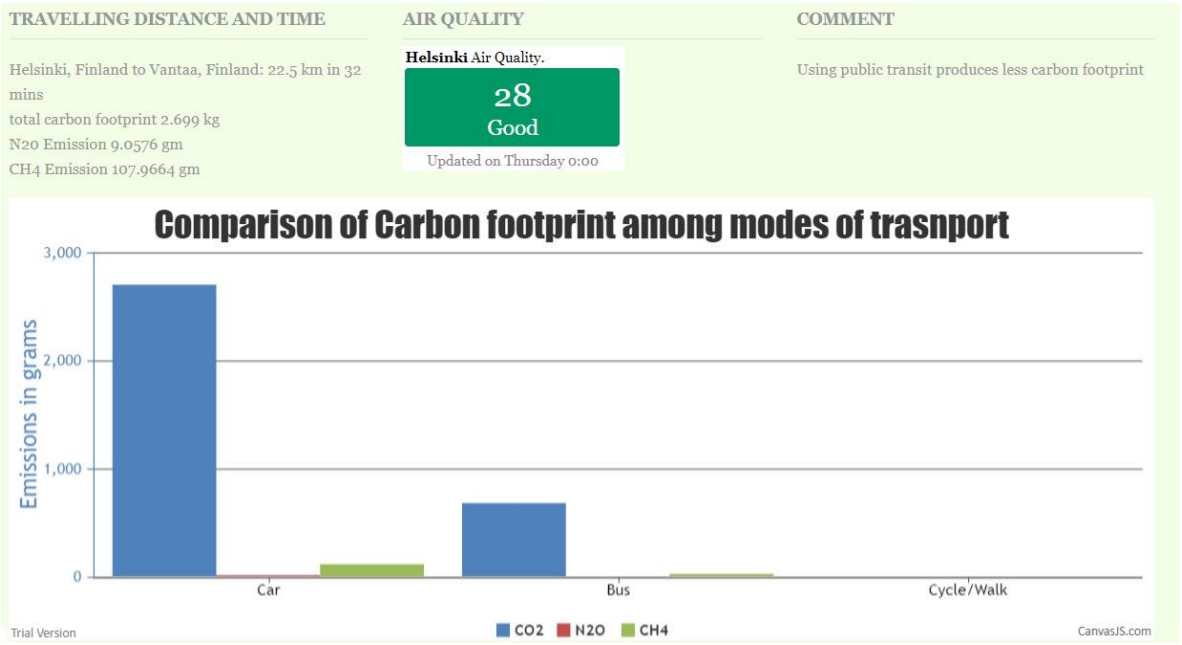

Figure 7. Sustainable Smart City Service in form of the Green Commute App.

3.3.3 Evaluate user experiences

In the last phase, the web application was shared through social media websites such as Facebook groups to let people of Helsinki use it and survey was made on their experience. According to Jakob Nielson there are many ways to evaluate a user interface for an application, however in most cases due to lack of time and experienced evaluators, researchers tend to heuristic evaluation. It is a good approach to identify cosmetic and functional problems of a system. The method does not require to train the users, they can simply find out their likes and dislikes just by looking or using the application and then answering a set of question or giving points to particular features of the application [55]. To be more specific heuristic evaluation is a relaxed usability engineering method to evaluate user interfaces to detect issues with the system interface. Actually, to perform this evaluation a set of design principles re followed [56]. In this research the to collect user experience 10 design principles of Jakob Nielson was considered [52]. The principles are explained in the following,

I. **Visibility of application status:** The status of the application should always be visible to the users. It should provide appropriate replies within understandable time to keep them interested.

II. **Correlation with the real world:** The application should not visualize such content that cannot be correlated by the user with real world context. It should produce results in common language with words, phrases and ideas understandable to the user group making them come forward in a logical and natural order.

III. **Access control and openness of users:** It is common that users will make mistakes during their functions and will require a plainly stamped "emergency exit" to leave unwanted state without roaming around the site unnecessary. The app should support undo and redo.

IV. **Consistency and standards:** It should not be the case that the users have to investigate the meanings of the results and situations in different forms and actions that may have the similar meaning.

V. **Error prevention:** An Application is much better when it acknowledges the problems and provide understandable error messages to the users. There should be confirmation messages before important actions being set in the system.

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VI. Acknowledgment instead of review: Limit the client's memory stack by making items, activities, and alternatives unmistakable. Directions for utilization of the framework ought to be unmistakable or effortlessly retrievable at whatever point suitable.

VII. Adaptability and effectiveness of utilization: Accelerators — concealed by the novice users — may regularly accelerate the communication for the regular users with the end goal that the framework can take into account both unpracticed and experienced users. Enable clients to tailor visit activities.

VIII. Stylish and Moderate plan: The comments and information should not contain irrelevant data. Irrelevant data mixed with actual information reduces the visibility of the results produced by the application, thus decreasing user appeal.

IX. Support to identify, diagnose, and recover from errors: Messages to the users during an action or in case of an error must be explained in simple language, directly indicating to the problem with a possible solution.

X. Help and documentation: In most cases a good application would be that does not require documentation. However, It is necessary to provide explanation of the system to help users get across the application and receive best results by following appropriate steps.

The principles are formulated into questions and statements during the evaluation period to receive the best results from the users. During the evaluation the main target has been to know more about the experience using the new idea of combining environmental data with a regular maps application, so rather searching out problems, it was more to justify the design approach.

4. Results

The result of this research has been achieved through two individual surveys. The first survey, which is the part of the heuristic evaluation was completed by 53 people living in the Helsinki city area and the second one was a closed questionnaire conducted with eight developers working the IT industry in Helsinki.

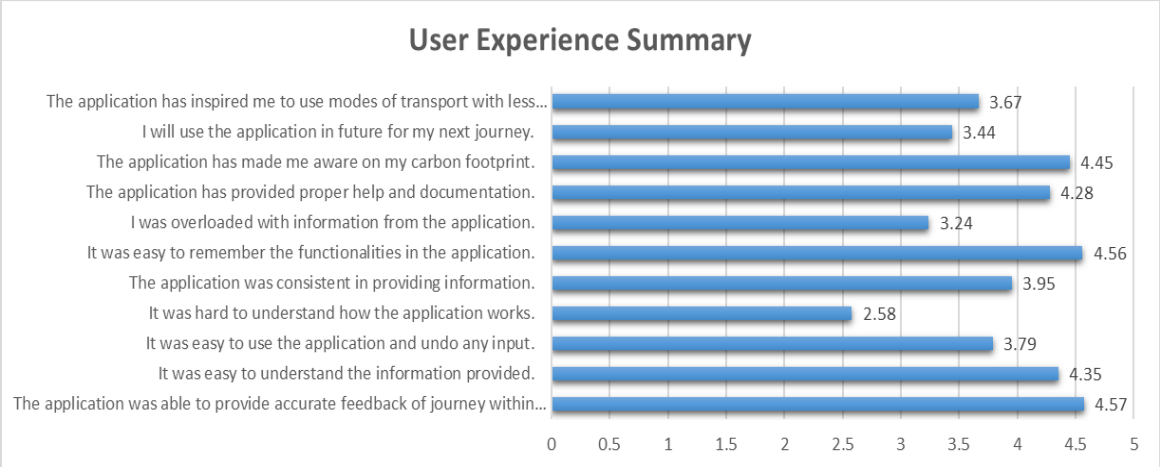

Figure 8. User Experience Summary on the usability of the application.

The figure 8, explains the overall user experience with the developed application which represents the combination of environmental data with smart city application. Users were given a set of 11 statements and they had choices to mark the statements in five levels of their feeling on the application. Starting from Level 1, which is strongly disagree, then disagree with level 2, level 3 if neutral, then 4 if agree and finally if they strongly agree with the statement it is counted as level 5. According to design principles explained earlier a system should provide information within a reasonable amount of time and from the summary it can be inferred most users agree that the feedback on the journey is received in time. Though users have neutral feeling about the access

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control of the application, but they agree that the information provided is easy to understand. The application also had good correlation with the real world and it was developed with the inspiration from a maps application. Thus, it was not hard to understand the work procedure of the application and the users disagreed on the statement that the application was tough to along with. The consistency of the application was also admirable as user almost agreed to the point and it can be understandable as the results of the service depends on various open source APIs, which has their own criteria and specification of providing information. Later, it can be perceived that users were positive on recalling the functionalities of the application and the resource on user manual. Alongside user experience, it was also verified if the idea of such service would be helpful to make inhabitants of the city to choose a better mode of transport in terms of environment sustainability and most users were nearly positive to the thought.

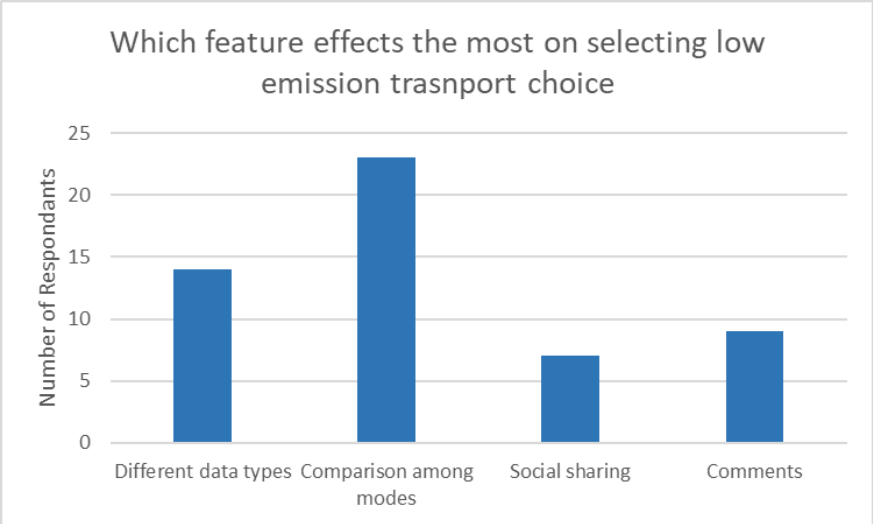

Figure 9. User view on most effective feature to promote low carbon emission vehicle choice.

Alongside user experience, respondents were also asked to choose according to them, the most effective feature to motivate them selecting the mode of transport with low carbon emission. In the application, 4 features that passive motivate sustainable behavior; the different data types on surrounding environment, comparison among different modes of transport according to their quantity of air pollutant emission, social sharing of personal choice and comments provided through the system. It is noticeable from figure 9, that users tend to actualize real data and comparison rather than social sharing and static comments. They prefer visualization of pollutant levels for different modes and as the graphical representation used in the system was best suited for both experience and inexperience users the result is obvious.

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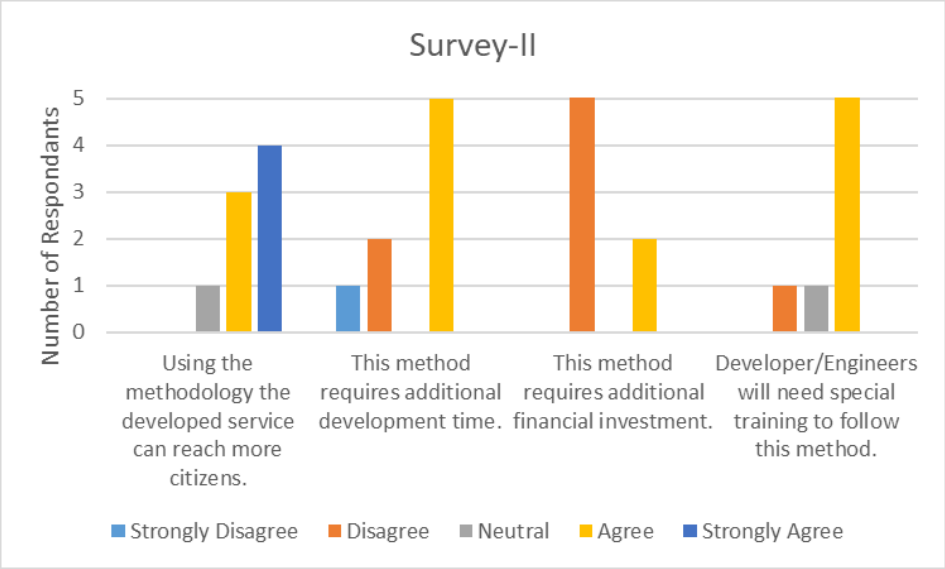

Figure 10. Perspective from Software Professionals on the method.

In the second survey, in total 8 Software Developers and Engineers responded on 4 topics to judge the method itself. The survey was conducted over Online voice calling service, in terms of their point of view presented in the figure-10, the approach would be useful to get attention of the people living in the city, as inhabitants of the city will be involved in the innovation and design, they can learn about the service beforehand its deployment. On the other hand, it is expected from the respondents that the developers or Engineers would have to give special attention and need extra training to follow this process to develop sustainable smart city services.

5. Discussion and Conclusion

The section will discuss on the overall aspects of the research, its direction towards solving the research question, challenges, its limitation and the impact analysis of sustainability.

Research Question 1: How to design sustainability into smart city services following Living Lab methodology?

Smart city services can be designed in many ways; however, it was a challenge to relate sustainability specifically environmental data into these services. The research has been focused to explain the need of the environmental data and what impact it may have by combining such data to regular smart city services. Thus, it has followed an innovation approach to design the service involving stakeholder who are for this case the inhabitant living in a smart city. The research has kept it focus on acceptability of the service by following standard design guidelines and taking user perception into account in each step of the process.

The process shifts from the traditional stages of software development and involves future users in the development process. This thesis shows an overall path from requirement analysis to testing the smart city service with real users. It helps to understand the perspective of people living in the city towards sustainability. In the beginning, many were unaware of the effect of carbon footprint, although having the basic concept of it. Throughout this process by involving them into the system and integrating environmental data in the smart city service has made an impact on their acceptance towards additional data along information of regular transportation service. The learnings that could be passed on for future reference would be three key factors in designing sustainable smart city services.

First, referring to the earlier chapter, people living in the city are considered as the main users of the smart city service. Therefore, users should be involved in the development process in active manner.

Second, prototyping from very early stage is necessary while dealing with novice users. It is easy for them to understand the target and provide valuable feedback for the future product.

Third, evaluation from users in each step or each rotation makes helps to receive knowledge on the service, such as what are good features, the bad designs, what is needed and what not.

The research has kept it focus on acceptability of the service by following standard design guidelines and taking user perception into account in each step of the process. It assisted the research in infusing sustainability in smart city services.

Research Question 2: What is the experience of the users in terms of viewing environmental data in case of the service presented in this research?

Combining environmental data with regular smart city services is a new approach to inform citizens on the emerging natural occurring. People are attracted to visual representation than static information. Therefore, the application provided important data for inexperienced users in an easy and understandable way, that it was well appreciated by them. All in all, the quality experience of the application functionalities was achievable by taking into measure appropriate guidelines of understanding user requirements from the start of the process.

5.1 Sustainability Analysis

Sustainability in software can reform in different ways. A sustainable software has to endure the changes in circumstances, alongside it should have good effects in long run. Sustainability in software does not concern only the environment, it has effect on individual as well in the society. In addition, the technical sustainability is a concern in software system to ensure its endurance. In general, software practitioners, tend to focus on ensuring long term service of the software [57]. It is inevitable that software systems have a great impact on our daily life. It can be expected that the three dimensions of sustainability, social, economic and environmental dimensions are likely to be affected by it [58].

The sustainability impact of a software service can be analyzed by the Becker et al, 2016 model [57]. The model has 5 dimensions to analyze the impact; they are economic, Technical, Environmental, Social and Individual. The impacts are categorized in three section, Immediate, Enabling and Structural.

Immediate impact points to the compete life cycle of the software system. Then, the opportunities it enables after it's usage over a long duration are the Enabling effects. Later, the changes that are recognizable at a large scale due to the system, are the Structural effects.

The web application will be used individually by each user in their daily life, thus it has immediate effects on a person. It provides many information on the environment, which increases personal knowledge. The immediate impact of service is that it provides environmental information depending on the choice of journey. Therefore, it enables the users to choose transport with less carbon emission and reduce individual carbon footprint. Moreover, the structural impact would lead to a sustainable lifestyle. Then, with the increase of personal knowledge, people in living the society will become concise on the social impact of low carbon emission transport which in long run may lead to more sustainable community. Economic sustainability is achieved as this service enable user to move from personal vehicle to public transport and public transport to cycle or walking, which will enable users to save money and in long term as use of public transport increases Government can earn more revenues. Though the environmental impact is passive, due its dependence on user motivation, but increasing personal awareness is an immediate effect to environmental endurance. Technically the application also remains sustainable, by using modular architecture new data APIs and sources can be integrated with the application to modify or update the service.

5.2 Limitations

The research work discussed in this report was focused on presenting an idea of bringing together the smart city services and services or data sources related to the environment. Though the demonstration of the service is centered towards the transportation system of a city, the research can

be deployed for other areas of smart city. For instance, in case of smart building or houses, different data sources can be used to provide house residents on their daily activities to take on the sustainable decision. Alongside combining these two different services with individual functionalities the research also focused on adapting to the user involvement approach known as Living Lab Methodology. Though following the methodology, the idea was successfully implemented, however there are some issues that bounded the research. The inclusion of inhabitants of Helsinki city was not consistent and it was not possible to include many users. The assumptions made in the results points to a small number of people and a larger participant could have ensured appealing results. On the other hand, a limited number of data sources were used in the final developed service. The selection of data sources or services depend on the feature they provide and if that service can be related with the application to provide understandable results. Dependency on the availability of these services limited the application to provide only information regarding transportation and air quality.

Supplementary Materials: None

Author Contribution: Conceptualization, Jari Porras; Data curation, Md Tawseef Alam; Funding acquisition, Md Tawseef Alam; Investigation, Md Tawseef Alam; Methodology, Md Tawseef Alam and Jari Porras; Project administration, Md Tawseef Alam and Jari Porras; Resources, Md Tawseef Alam; Supervision, Jari Porras; Validation, Jari Porras; Visualization, Md Tawseef Alam; Writing – original draft, Md Tawseef Alam; Writing – review & editing, Md Tawseef Alam and Jari Porras.

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Conflicts of Interest: The authors declare no conflict of interest.

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