Masters Program in **Geospatial Technologies**

WEB-BASED PPGIS APPLICATION FOR PARTICIPATORY SPATIAL PLANNING IN CONTEXT OF BIKEABILITY

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ABSTRACT

The spatial planning processes are complex and require public participation to get insights about important problems and development of the neighborhood from the communities during final decision-making. The traditional participatory methods offer limited two-way communication just inform the public rather than to obtain suggestions from them and few public can participate due to time & location restrictions. Due to low public empowerment, they do not know how their participation can influence the spatial planning and decision-making process. This study tries to design and develop the web-based Public Participation GIS application with the integration of the internet, public participation, and GIS technologies to increase public participation during spatial planning and decision-making to overcome the limitations of traditional participatory methods. The web-based PPGIS application development is based on open-source technologies and allows the participants to visualize spatial data layer, perform spatial analyses and contribute to increasing and improving the bikeability of the city. The user study experiment is conducted to evaluate the usability and usefulness of the application. The evaluation results show that the web-based PPGIS application is easy to use with a System Usability Scale (SUS) score of 84.6 and an effective approach to increase public engagement and give suggestions on the spatial planning process and decision making.

KEYWORDS

Spatial Planning
Participatory Planning
Public Participation
Public Participation Geographic Information Systems (PPGIS)
Web-based Public Participation Geographic Information Systems (WPPGIS)

ACRONYMS

PP	Public Participation
GIS	Geographic Information System
PPGIS	Public Participation Geographic Information System
HTTP	HyperText Transfer Protocol
HTML	HyperText Markup Language
CSS	Cascading Style Sheet
JS	JavaScript
API	Application Programming Interface
JSON	JavaScript Object Notation
BI	Bikeability Index
SAA	Service Area Analysis
KML	Keyhole Markup Language
DBMS	Database Management System

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1 Introduction

1.1 Background

The urban planning and development is an important process for decision-making for every local and regional scale government. The activities of urban planning are performed and controlled by only urban planning professionals [1]. From the last decade, public involvement in the urban planning process has been becoming important [2-4].

These days, government officials and researchers are searching for methods to increase the participation of the public during the urban planning and decision-making process, unlike the past years in which the urban professionals made their decisions without considering any information from the public side [5,6]. The public participation in urban planning also changes the traditional planning approach from top-down to bottom-top models and lead to a sustainable and effective plan [7].

Public participation not only does deliberate hearings but also involved in the planning and decision-making process [8]. Effective public participation is a two-way communication process that includes sending the information to the public first and getting their concerns and suggestions back regarding the information [9]. According to Huxhold, knowledge, and information are always included by the participants to make good decisions [10].

The public meeting is still common and mostly used for public involvement in the urban planning process [11]. The disadvantage of public meetings is that they are carried out at a particular place for a fixed time. Due to which only a limited number of public participants are involved in the planning and decision-making process. Therefore, new tools are required to be developed that can support public participation in the urban planning and decision-making process [1]. In the past various traditional methods such as media, surveys & polling, workshops and interviews had been used for public participation in the urban planning and decision-making process [8, 12].

In the 1990s, the usage of modern computers, desktop GIS, and decision support software has been started to facilitate and support collaboration and public participation in urban planning and decision-making processes [4, 13]. The GIS is used to support the public involvement in the spatial planning and decision-making process and often it is termed as public participatory GIS (PPGIS) [14]. The term PPGIS was introduced first at the workshop organized by the National Center for Geographic Information and Analysis (NCGIA) in the U.S and defined as "A variety of approaches to make GIS and other spatial decision-making tools available and accessible to all those with a stack in official decisions" [15]. Talen indicates the influence of public participation and collaboration in the spatial planning processes [4]. Similarly, Haklay et al. explain the PPGIS as the use of GIS by the public with the purpose to participate in the spatial planning processes [16].

The traditional GIS software has a high cost and complex design of software which limits the usage of the software by a small number of groups such as GIS technicians, urban planners, and researchers [17]. The insufficient development has been made to support the public participation to join and collaborate in the GIS-based urban planning processes [18].

In recent years, internet technologies have been improved rapidly and PPGIS applications have also started using the opportunities of the internet and are often called online PPGIS or web-based PPGIS [3,19,20]. The web-based PPGIS uses Geographic Information Systems (GIS) and web-based applications to deliver the information to participants and get back their concerns and suggestions regarding the planning process. The problems caused by traditional public participation and desktop GIS software and can be solved by web-based PPGIS [3,18]. For example, public participants can join the process from any place and time that has internet service. The other advantage of web-based PPGIS is that public participants do not have to involve in the complex processes of GIS for spatial analysis. The Web-based PPGIS application provides a platform for visualizing & exploring the spatial data, perform spatial analysis with the public input that leads to good decision-making [18, 21].

The web-based PPGIS system not only needs to upload on the website to make it accessible for the public to participate in the planning and decision-making process but also to make it efficient for the participants to perform the particular tasks [22]. If the web-based PPGIS system's usability is not efficient and satisfactory, it would cause problems such as decreasing the number of public participants in the urban planning participatory process.

The increase in traffic vehicles in urban cities has created many problems and has become a major challenge [23]. The transport sector released around 23 percent of carbon dioxide (CO_2) in the atmosphere which is the highest contribution as compared to other sectors such as construction, production of electricity, and industries [24]. The measures have been taken to increase the usage of renewable energy resources for the vehicles but still majority of traffic vehicles are running on fossil fuels. The transport activities consumed nearly 80 percent of the energy resources majorly by light vehicles such as cars. The developed countries are experiencing a high use of personal vehicles for daily travels and a higher number of personal vehicles ownership can be directly related to GDP (Growth Domestic Product) per capita. The developing countries are also experiencing a rapid increase in the usage of personal vehicles due to the availability of the poor public transport system to fulfill their daily traveling needs. The rapid urbanization and the common perception that the personal car is a symbol of social status in society are factors to increase the number of vehicles [25]. They lead to traffic congestion, injuries in traffic accidents, and an increase in noise and air pollution which have a negative influence on the environment and negative impacts on an individual's health [26]. The time spent in traffic congestion also causes the economical burden as revealed in a study conducted by INRIX which shows that UK, Germany, and U.S.A bear 461 billion dollars a year due to traffic congestion [27].

A possible way to improve this situation, an alternative transportation mode such as active transport which is defined as walking or cycling for transport purposes to motorized vehicles is needed in the society through good transport and urban planning. The authorities can increase the use of active transport modes by improving the existing conditions of walking and cycling and public transport system in the cities. It provides more possibilities for increasing social interaction between the public and improves the accessibility of facilities in a city and reduces traffic congestion, accidents, and environmental problems [25].

The government and private organizations around the world are trying to promote the use of bicycles to make a sustainable transport system for cities to support the environmental crisis [28,29]. The bicycles not only provides environmental benefits but also economic and social benefits and reduce traffic congestion in society. The bicycle mode not only helps to solve problems stated above but also brings a positive impact on public health individually and improve the quality of life [30].

Many urban cities are trying to improve their cycling networks to increase the cycling mode and replace motorized transportation for short distance traveling. Bikeability is a term used to describe and determine the level of interaction between the factors associated with bicycling [31]. The bicycle lane conditions, trip distance, parking, and other factors have a direct impact on the bicycle trip. The bikeability becomes a frequent term in transport and urban planning. The approach is used to determine the bikeability by identifying the factors from the literature which have an influence on the people for bicycling then assign the weights to these factors according to their importance and determine the bikeability score for areas and classifying them on bikeability regions and non-bikeability regions for bicycling.

The spatial analysis can be used for evaluating the existing bikeability in the city by considering different parameters that are correlated to bikeability. By, these bikeability maps, the planners can make future transportation planning and policy-making, or the public can be engaged during the public planning process to improve and increase the bikeability in the city. These spatial analyses identify the potential locations for new bicycle infrastructure.

1.2 Research Context

1.2.1 Research Problem

The traditional public participation methods have limited public involvement in urban planning and decision-making as it totally depends upon the number of participants involved during the public meeting. The main reason for limited public participation is that the used communication methods are old, less productive, interactive and effective, limited access to the information, fixed time and accessibility problems as compared to the new participation methods particularly when investigating the geospatial data. During public meetings, workshops, or seminars, the urban plans and development strategies are presented to the public participants in the form of paper or hardcopy maps to announce the planning solutions [32,33].

The recently developed web-based PGGIS applications do not have an effective communication platform to improve public participation during urban planning and supports limited participation. For example, public participants can only explore, visualize, print, share, and download the data using the application map. The public participant cannot edit and contribute to the application map. However, providing the only access to the planning information is not enough for the participants to be fully engaged in the participatory planning process.

The implementation of web-based PPGIS using commercial technologies is costly for public participation during urban planning. Therefore a framework is needed that can reduce the cost of design, development, and implementation of web-based PPGIS applications.

Although there is rapid growth in Information and Communication Technology (ICT) and the development of many PPGIS applications but still there are some issues to the existing webGIS based public participation applications for urban planning that need to be improved. So, this research tries an effort to discuss and solve the existing problems in the PPGIS and public participation methods used during the urban planning, development, and decision-making process.

1.2.2 Research Objective

The main objective of the thesis is to design, develop and implement a web-based PPGIS application to support public participation in spatial planning processes for improving the bikeability of a city and identify the factors which contribute towards the bikeability of a city. The web-based PPGIS application will use the open-source libraries and Application Programming Interface (API) for visualization and allow users to perform spatial analyses tasks related to bikeability. To achieve the main objective, the following specific objectives are undertaken:

1. To identify factors that contribute towards bikeability by reviewing the previous scientific literature and develop a bikeability index
2. To develop an open-source web-based PPGIS application for improving the bikeability
3. Enable users to perform spatial analyses in the context of bikeability using the web-based application
4. To evaluate the usefulness and usability of the web-based PPGIS using user-study experiment

1.3 Study Area

Chicago city is located 176 meters above sea level on the shores of Michigan Lake in Illinois state of the USA [126]. The Chicago city has 77 neighborhoods with a total area of 600 Km^2, a 2.7 million population, and a third populous city in the USA. Chicago is selected as a study area for the development of web-based PPGIS application because it has the second-highest percentage of peoples that use a bicycle for traveling. In 2016, Chicago was given the title of "USA Best Bike City" by Bicycling Magazine. Currently, Chicago city has more than 200 miles of different bicycle paths [127]. The figure-1 shows the overview map study area.

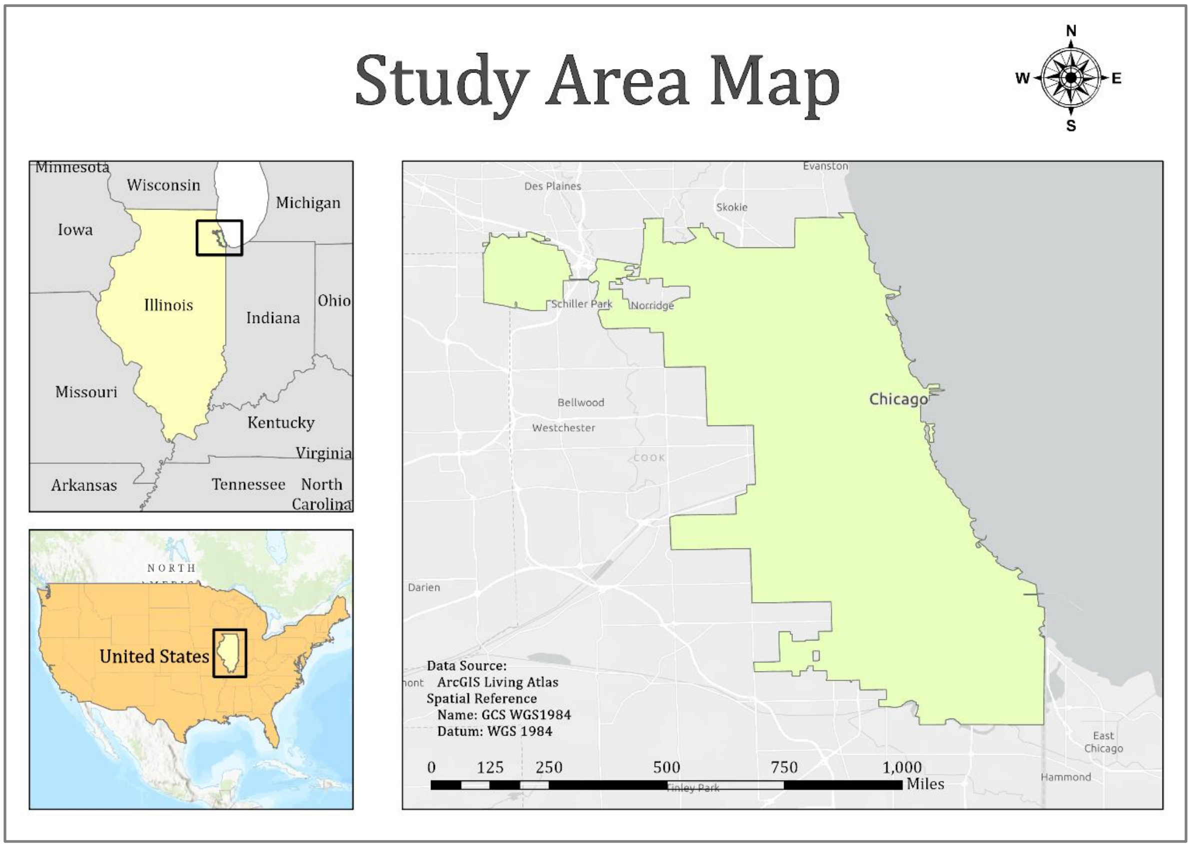


Figure 1: Study Area Overview Map

The bicycle safety is also an important concern in improving the bicycle infrastructure and facilities. From 2015 to 2020, 7129 bicycle accidents have been reported in Chicago city [128]. As the number of bicyclists is increasing in the city, the number of bicycle accidents is also increasing. The figure-2 shows the graph that how the number of bicycle accidents is increasing from 2015 to 2020.

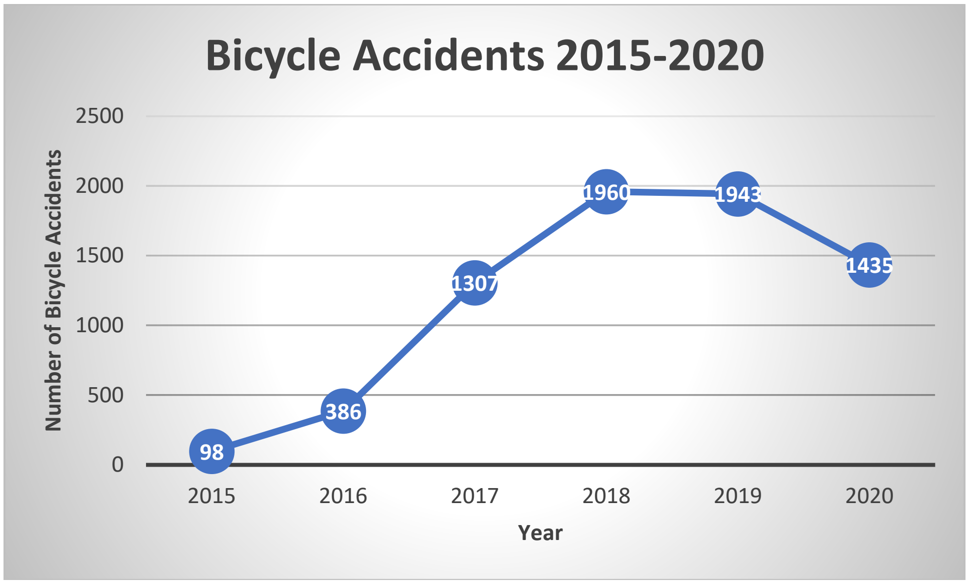


Figure 2: Bicycle Accidents Graph 2015-2020 [128]

1.4 Thesis Structure

This thesis consists of seven chapters.
Chapter 1 is the introduction that provides an overview of public participation methods, PPGIS, and web-based PPGIS application with its importance. It also describes the research problem and research objectives.

Chapter 2 is the Literature Review that describes the importance of public participation in urban planning and decision-making and existing methods for public participation. It also explores the role of ICT in the web-based PPGIS application development by reviewing existing web-based PPGIS applications. In the last part of the chapter, what is bikeability, and measuring bikeability is explained?

Chapter 3 reviews the existing technologies that are used to design and develop the web-based public participatory application.

Chapter 4 & 5 explains the used methodology for this study. The chapter 4 reviews scientific literature to identify the factors that contribute towards bikeability and explains the methodology for developing the bikeability index. Similarly, chapter 5 explains the procedure and technologies that are used to develop the web-based PPGIS application for this study

Chapter 6 describes the evaluation process of a web-based PPGIS using a user-case study.

Chapter 7 concludes and summarizes work completed in this thesis.

2 Literature Review

This chapter will explain the concept and importance of public participation during the spatial planning and development processes and provide a fundamental structure for web-based PPGIS applications that are studied in the literature review. In the first section of the chapter, the importance of public participation and the traditional participation methods are discussed. After this, the evolution of Information & Communication Technologies (ICT) with Public Participation Geographic Information System (PPGIS) is discussed.

2.1 Why and What is Public Participation

To understand the concept of public participation term, the understanding of the public and participation word is important. The word "public" indicates the citizens or group of individuals who are involved in the process and will be affected by the outcomes of the process. The word "participation" means a process in which the public is involved to receive information and give their opinions regarding this information to make an acceptable decision [35]. So the term public participation means the involvement of the citizens in the decision-making process with the objective to obtain an acceptable decision and good solution regarding the problems [36,37]. The public participation process provides many benefits in several ways such as support and acceptance of the decision and gathering local knowledge and feedbacks [38-40].

The traditional methods of urban planning mainly depend upon the planner's knowledge, but now it has been changing towards a multi-sector approach and involve citizen groups and other organizations in the planning process [41]. The traditional urban planning top-down approach is failed to obtain and manage sustainable urban planning plans because in many situations the opinions of minority groups and poor peoples are not considered [41,42]. According to the laws of several local-government and municipalities of North America and European countries, they need a certain level of public participation during the decision-making process [43].

2.2 Level of Public Participation

The level of public participation indicates the stage level in which public groups are involved during the decision-making process. The level of public participation can be understood with the help of a participation ladder. The practitioners are using the participation ladder framework to plan and investigate the public participation processes.

The first public participation ladder was introduced by Arnstein in 1969 [44]. The ladder structure describes the different levels of powers given to the public in the decision-making process. It also helps to understand how power is distributed between the public and the authority during the participatory process.

The Arnstein participation ladder is divided into eight rungs and each rung has a specific level of involvement and power-sharing between the public and authority during the decision-making. The bottom rungs of the ladder represent the lower levels of participation and power-sharing and whereas, by moving up towards the upper rungs of a ladder, the levels of participation and power-sharing are increased between the public and authority respectively. At the bottom-most rung of a ladder, the authority only delivers the information to the public, and at the top-most rung of the ladder, the authority transfer power to the public groups to make decisions. The figure-3 shows the framework of the Arnstein public participation ladder.

The Arnstein participation ladder framework involves the public at different levels of participation based on their knowledge [45]. The main disadvantage of this ladder framework is that it only focuses on public empowerment and does not find important discussion features such as "How many public participants and what levels of participation are required for an effective decision-making?" [130, 131].

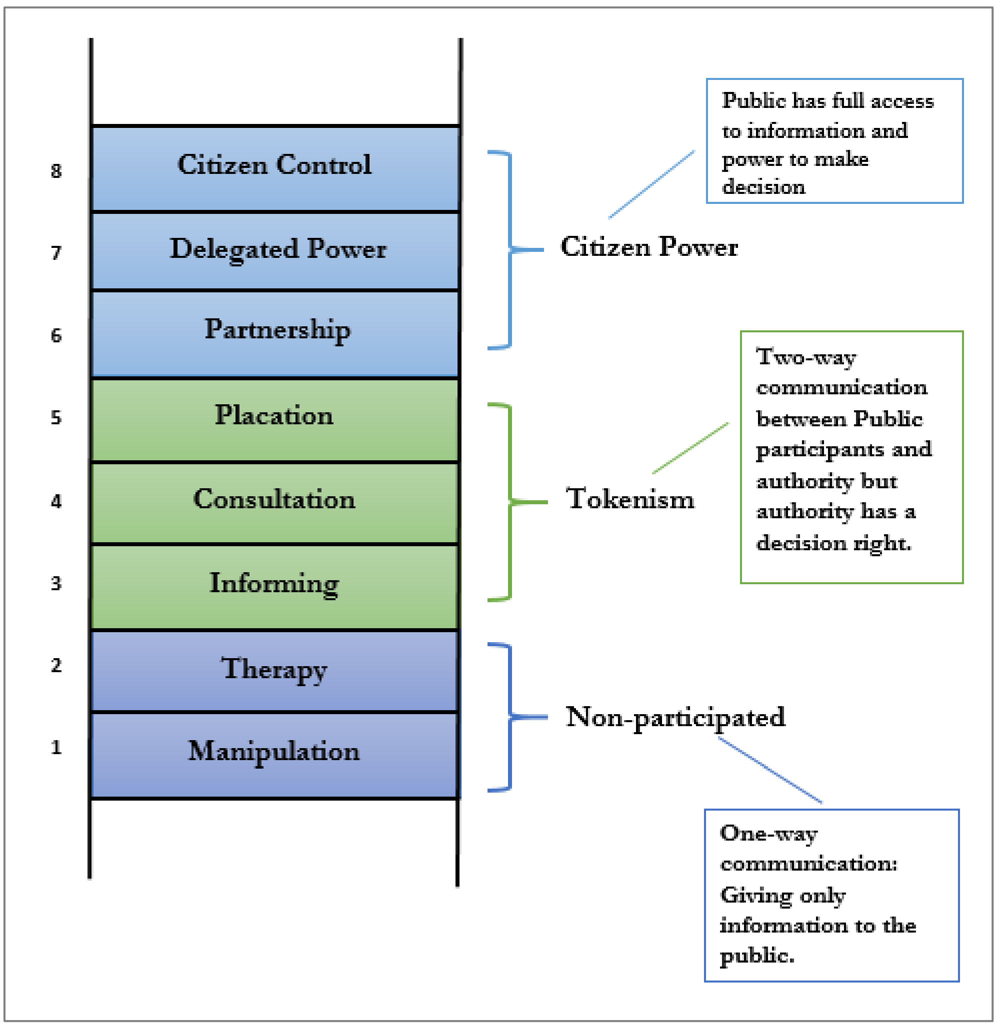


Figure 3: Modified Arnstein Public Participation Ladder [44]

In 1993, Weidemann and Femers proposed a six rung public participation ladder framework based on the Arnstein participation ladder [46]. In their ladder framework, public participation increases as the public have more access to information and powers for decision-making. The important characteristic of this participation ladder is that the upper rungs can be reached only if the conditions of the bottom rungs are fulfilled. The figure-4 shows the proposed framework of the Weidemann and Femers public participation ladder.

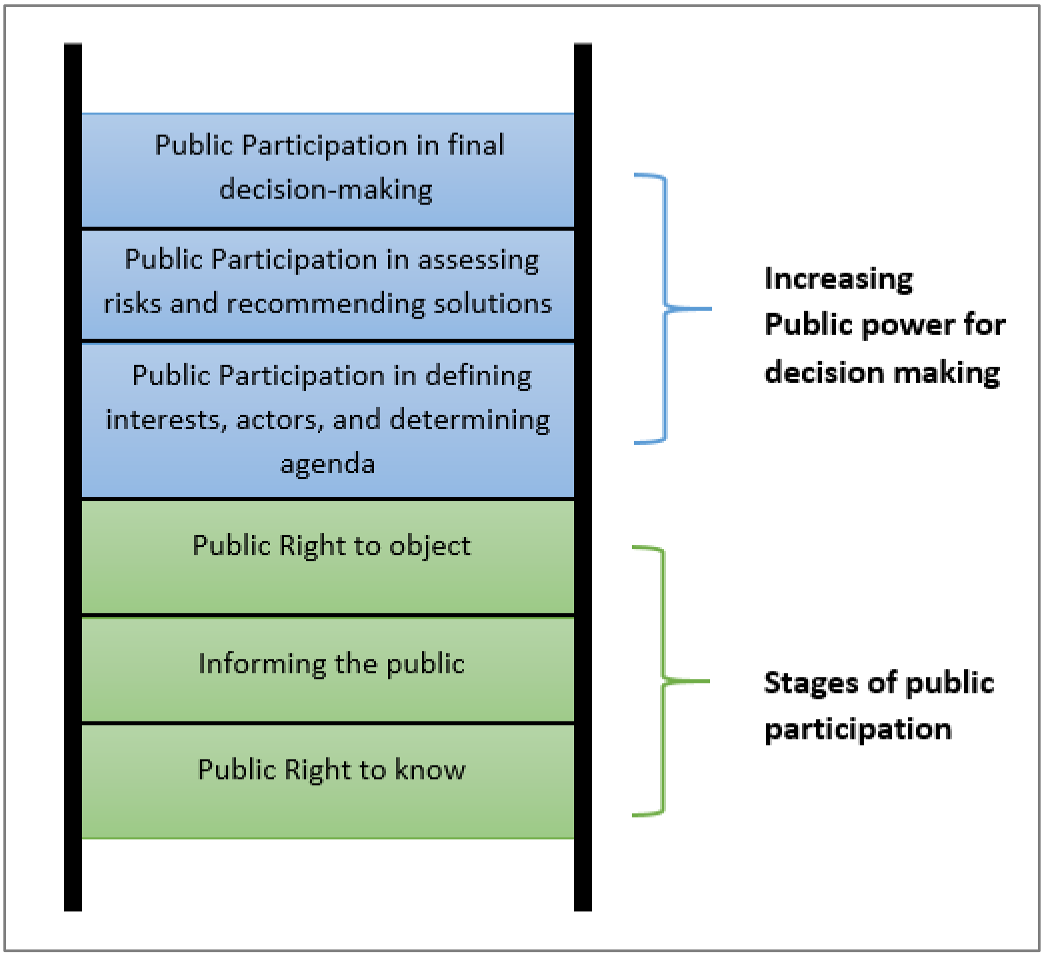


Figure 4: Weidemann and Femers Public Participation Ladder [46]

The Oregon State Citizen Involvement Advisory Committee (CIAC) highlights the importance of the public participation during the planning processes supported by the public participation ladder framework designed by Arnstein and Wiedemann & Femers [47,48]. The CIAC of Oregon State gives five important reasons why the public should have to participate in the planning process and how it improves the outcomes of the process with the input of public participation [47-49].

The Oregon state CIAC presents the strategy for effective public participation that includes designing an effective public participation plan, giving and getting information to and from the public, and effective communication between the public and authority for exchanging information with the contribution of electronic media. The figure-5 shows the Oregon CIAC 5 reasons for Public Participation.

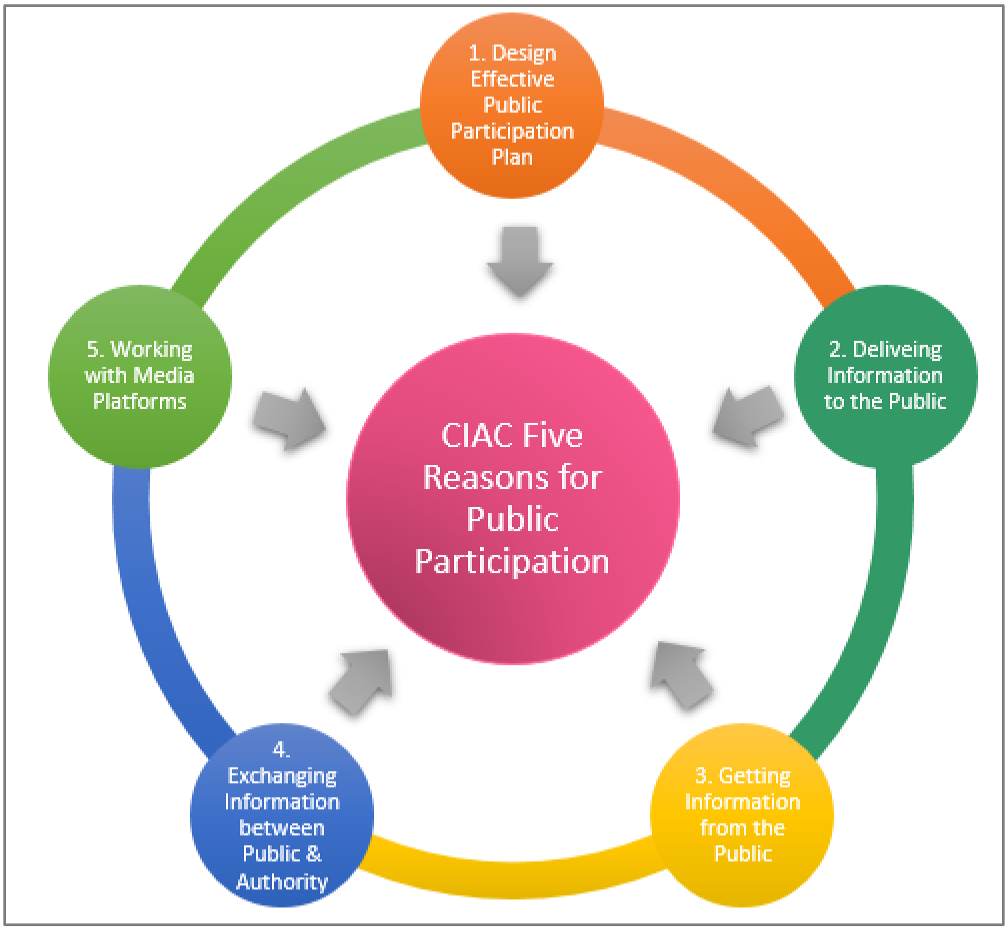


Figure 5: CIAC Five Reasons of Participation [50]

2.3 Shift to E-Participation Ladder

In 2002 Kingston has presented an e-participation ladder framework based on the Widemann and Femers ladder which starts with providing "Online Services" and ends with "Online Decision Support System" [51]. The e-participation ladder shows different stages for public participation based on communication levels between public and decision-makers authorities.

The bottom rungs of the e-participation ladder have only one-way communication to just give information to the public participants, but the top rungs of the e-participation ladder provide two-way communication levels. The figure-6 shows the proposed framework of the Kingston public participation e-ladder.

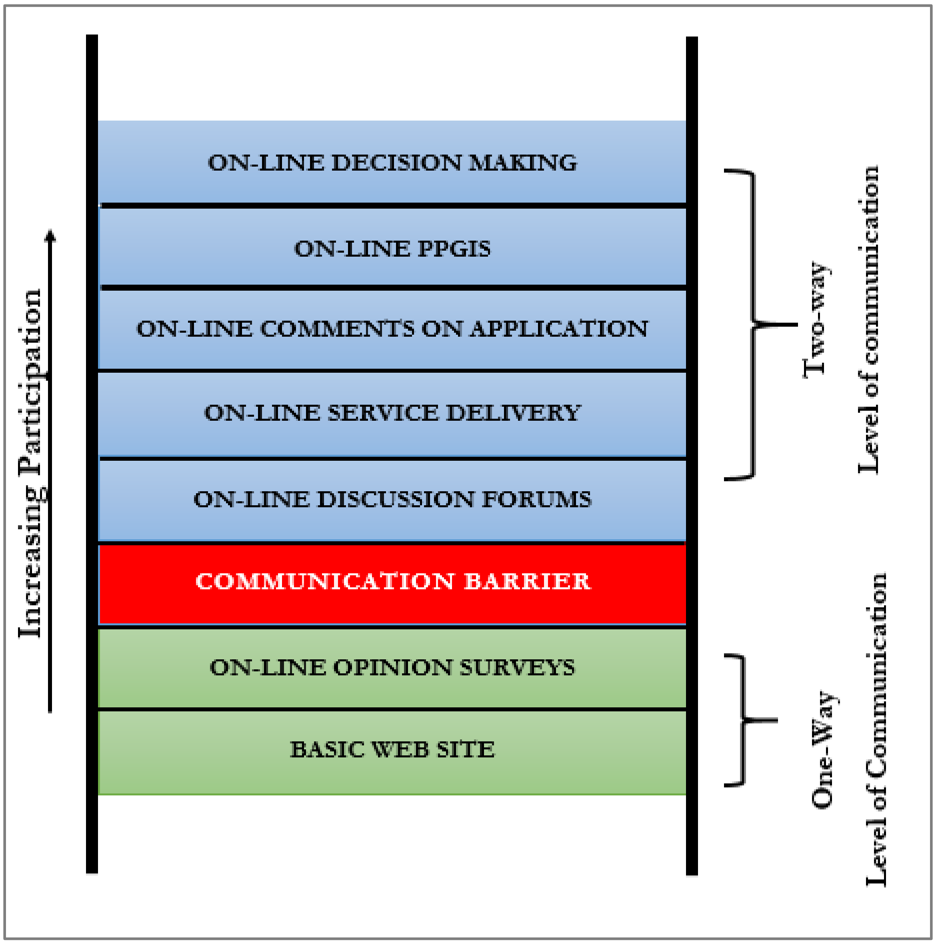


Figure 6: E-participation ladder framework for Public Participation [51]

For effective public participation, useful tools are required for giving access to information; getting information from the public and getting input into the decision-making process in a short period of time [52].

The shift from the traditional to e-participation methods and the advancements in the Information and Communication Technologies (ICT) over the last years have provided new possibilities to give and collect information in a short period of time. The rapid increase in the usage of the internet and the developments in the World Wide Web (WWW) uses new e-participation tools such as discussion forums, emails, online video meeting sessions, and surveys, etc.

2.4 Existing Public Participation Tools for Urban Planning & Decision-Making

The planning process has a specific objective that has to be achieved. For example, public participation in urban planning has objectives such as to involve and support the public in the planning and decision-making process. From the last decade, public involvement in the urban planning process has been becoming important to make sustainable and acceptable decisions [2,3]. Public participation not only does deliberate hearings but also involved in the planning and decision-making process [8]. Effective public participation is a two-way communication process that includes sending the information to the public first and getting their concerns and suggestions back regarding the information [9]. In the past various traditional methods such as media, surveys & polling, workshops and interviews had been used for public participation in the urban planning and decision-making process [8, 12]. The planners or decision-making authorities show their proposed plan on boards or using presentation slides which are still generally most used participatory methods to deliver the information during public meetings [11].

The table-1 shows the advantages and disadvantages of existing traditional methods to facilitate public participation in the urban planning process [8].

Method	**Description**	**Advantages**	**Disadvantages**
Media	Television, Radio, Newspaper, News Press Release	Notifying Information in real-time	No feedback or communication from the public
Public Meetings	Organization officials announce news and statements	Any participant can join and give their opinion	Limited number of public attend the meeting
Surveys & Polling	Identify public concerns & interests via email, website, and SMS	Collect large information from diverse public	Costly, Less response from the public
Workshop	Engaging the public via sessions and exercises related to something specific	Two-way communication	A limited number of participants

Interview	Private communication via meeting or phone	Get public concerns and opinions	Time-consuming & costly
Internet Network	Informing the public via the internet (websites)	Low cost and can reach more people	Everyone has not accessed to internet

Table 1: Advantages & Disadvantages in Existing Methods of Public Participation

The traditional methods for the public participation process are held by the government or non -government organizations for the involvement of citizens to make an acceptable decision and citizens could discuss their views during the meeting. The public meeting is held at a specific place and time which also limits the number of participants to involve in the planning and decision-making process [53]. The other main disadvantage of traditional public participation methods is the lack of effective communication platforms to exchange information.

2.5 What is Public Participation GIS (PPGIS)?

In the 1990s, the usage of modern computers, GIS, and decision support software has been started to facilitate and support collaboration and public participation in urban planning and decision-making processes [4, 13]. The traditional GIS is used for collecting, storing, exploring, and handling geographic data [54]. But it does not support the interaction tools between the group members while analyzing geographic data and public participation for the decision-making process.

The new form of public participation has been designed and named Public Participation GIS and Web-based PPGIS Application [55,56]. The PPGIS is a process of using GIS to collect information, facilitate public participation in the planning and decision-making process [57,58].

The term PPGIS was introduced first at the workshop organized by the National Center for Geographic Information and Analysis (NCGIA) in the U.S and defined as "A variety of approaches to make GIS and other spatial decision-making tools available and accessible to all those with a stack in official decisions" [15]. Talen indicates the influence of public participation and collaboration in the spatial planning processes [4]. Similarly, Haklay et al. explain the PPGIS as the use of GIS for the public with the purpose to participate in the spatial planning processes [59]. The table-2 shows the difference between GIS and PPGIS [60].

Factors	GIS	PPGIS
Focus	Only on technology	Integration of people & technology
Goal	Facilitate only policy-making authorities	Empower public participants
Usability Interface	Complex Interface	User-friendly Interface
Methods & functions	Multipurpose applications	Specific applications

Table 2: Comparison of GIS & PPGIS

2.6 What is Web-based PPGIS?

In recent years, internet technologies have been improved rapidly and PPGIS applications have also started using the opportunities of the internet and are often called online PPGIS or web-based PPGIS [3,19,20]. Laurini defines the Web-based PPGIS terms as "As a medium for exchanging information, ideas, and maps between all actors" [61]. The web-based PPGIS uses the integration of Geographic Information Systems (GIS) and web-based applications with participatory tools to deliver the information to participants and get back their concerns and suggestions regarding the planning and decision-making process. The figure-7 shows the integration of Public Participation, GIS, and Internet approaches with each other.

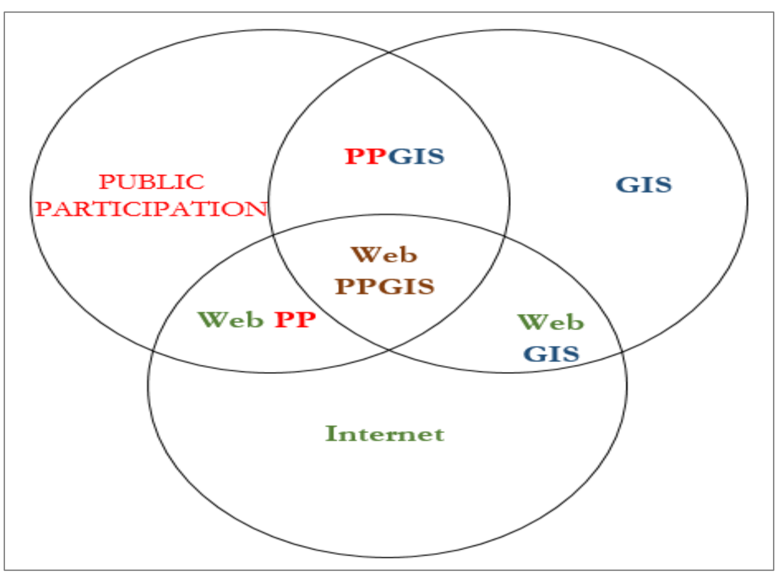


Figure 7: Internet, Public Participation, GIS and their integration [138]

The PPGIS projects have limited usage of the GIS software due to the high cost but the Web-based PPGIS applications are cost-effective and efficient [3,62]. The recent advancements in web mapping with the facility to give opinions are used to involve the public in the participation process [63]. The web-based PPGIS applications allow the public to mark their reports on a map and store this geo-referenced information in the database. In this way, it helps the organizations or planning authorities to find the accurate location of the reported place but also provides the chance to perform the spatial analysis. The advancements in Web-based PPGIS applications increase the number of participants to access the geographic information, visualize, and participate in the planning and decision-making process with any condition of time and place.

2.6.1 Review of Web-based PPGIS Applications

The following web-PPGIS applications are selected for further investigation. The web-PPGSIS applications are selected on the following specific criteria;

- The public has access to the data and tools
- The public can provide their feedback to facilitate public participation
- Provide GIS-based functionalities for useful decision-making and particip-ation
- Optionally, user-friendly web-based application

Virtual Slaithwaite United Kingdom:

The Virtual Slaithwaite project is the first web-based public participation in the United Kingdom to get public opinions about the future developments of their municipality [33]. The application was first developed in 1998 by the University of Leeds and redesigned in 2003 by using JAVA language [64]. The purpose of this web-based PPGIS application is to take important suggestions and comments on the map for future planning of the municipality.

The figure-9 shows the user interface of the application and provides the tools to the public;

- Access and visualize the geographic information
- Perform simple spatial queries (such as Where is this building located? or What is the length of the road?)
- Map navigation tools (zoom, pans)
- Submit suggestion/comments

The suggestion provided by the public are displayed on the map by using a small dot (flag) symbol, and it can be viewed by other participants [21]. This web-based PPGIS application has also a few drawbacks. The application performance during the display of geographic data is slow due to no usage of the map server. The maps are created by using the PERL language modules which are not supposed an optimal solution. The second drawback is that other public participants cannot contribute to the earlier created suggestions/comments.

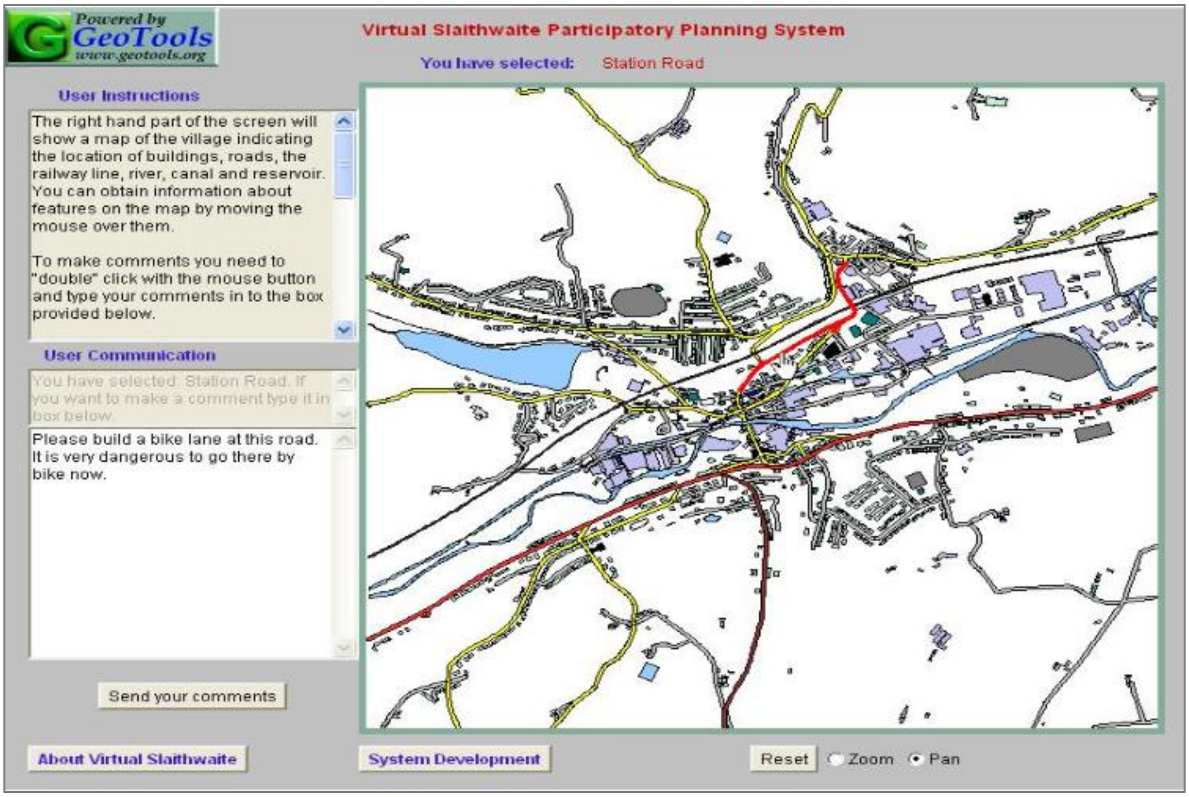


Figure 8: Virtual Slaithwaite Application Interface [64]

Orange County Interactive Mapping Application:

The city of Orlando has developed an "Orange County Interactive Mapping" web-based participatory application in United States of America. The application allows the user to extract the spatial information from different data layers and add suggestions or comments on the map [65]. The important advantage of this application is that the participant can send the map with his suggestion to the Board of County Commissioners. The figure-10 shows the user interface of the application.

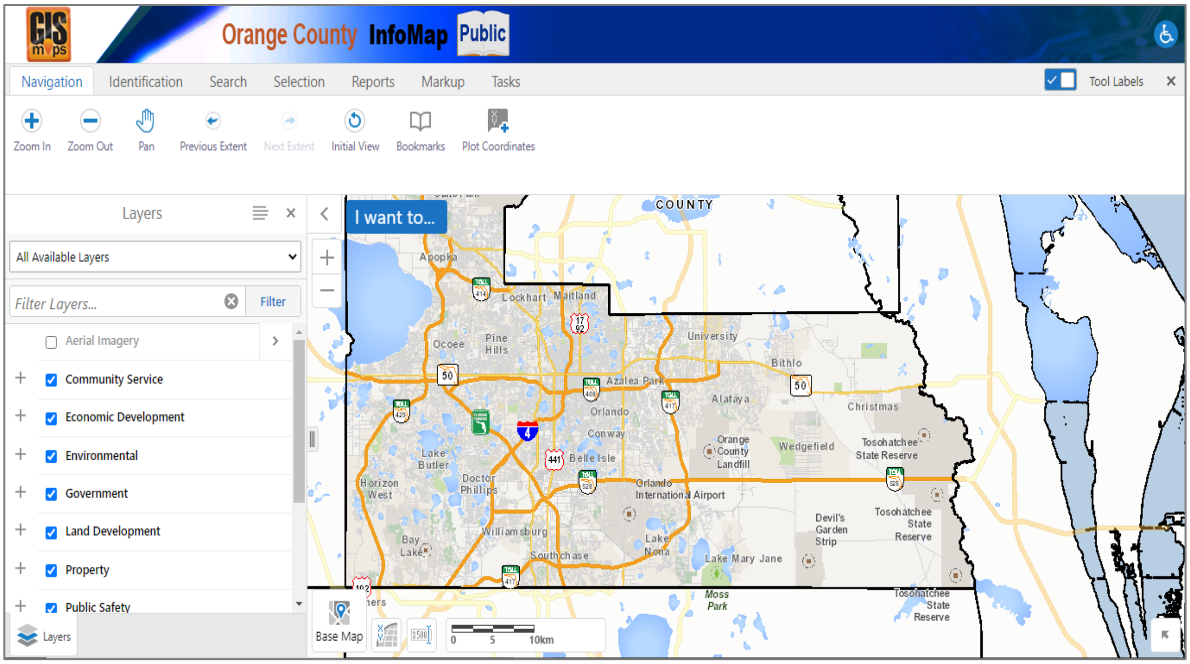


Figure 9: Orange County Interactive Mapping Application Interface [65]

MapChat Application:

The MapChat is an open-source web-based PPGIS application that allows the participants to share a map, draw features, add comments to the feature on the map in real-time with other participants [66,67]. The development of the first version of MapChat was started in 2005 by Brent Hall. The second version of MapChat was completed in early 2008 by Brent Hall with the collaboration of Michael G. Leahy to develop an interactive, effective and stable application [67].

The MapChat application helps the participants to draw features to point out the needs related to the planning projects on the map or give suggestions for better decision-making. The interesting component of this application is that the suggestions/comments are geo-tagged to the features on the map and other participants can also reply to that discussion. The figure-11 shows the geotagged chats on the map when the user clicks on the map features.

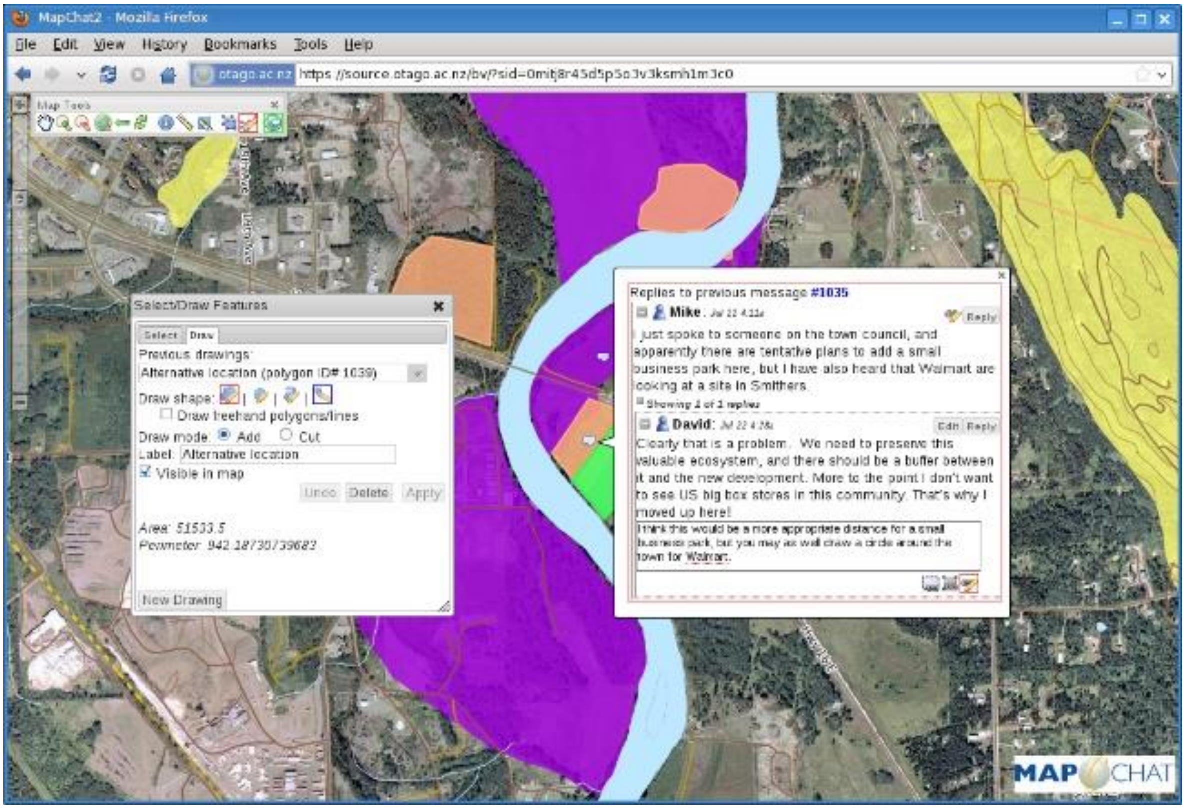


Figure 10: Geotagged Chat MapChat [67]

The objective of developing web-based PPGIS applications is to improve public participation in the planning and decision-making process efficiently and effectively. So, the evaluation of the web-based PPGIS applications helped the developers and planners to identify the weakness of the application. The table-3 shows the comparison of the selected web-based PPGIS applications based on some evaluation criteria. The "✓" indicates that the particular web-based PPGIS application has the respective functionality, "x" indicates that the application has not that functionality and "--" indicates that information is not available.

PPGIS Function	Virtual Slaithwaite	Orange County	MapChat
Data Selection	✓	✓	✓
Information Retrieval	x	✓	x
Perform Query	x	✓	x
Map Zoom & Pan	✓	✓	✓
Data Download	x	x	x
Real-time Discussion	x	x	✓
Signin Authentication	x	x	✓
Server Support	Perl Scripts	Map Server	--

Programming Language Modules	JAVA	DHTML	--

Table 3: Comparison of the selected Web-based PPGIS Applications

Similarly, Renate et al. compared the web-based PPGIS between Europe & the US due to their different planning processes and evaluate them based on the visualization, usability, and interactivity parameters by the group of 5 experts [68]. Seven web-based PPGIS applications were selected from the US and 5 applications were selected from Europe. They used a scale of 1 to 5 where 1 means very good and 5 means very bad. The figure-12 shows the table that summarizes the results of every expert and calculates the mean and median.

Evaluation Criteria		*US1*	*US2*	*US3*	*US4*	*US5*	*US6*	*US7*	*UK1*	*UK2*	*UK3*	*DE1*	*DE2*
Suitability of web application for the task	*MEAN*	2,8	2,2	2,3	3	2	3,2	2,5	1,3	2,2	2	1,3	2
	MEDIAN	3	2	2	3	2	4	2,5	1	3	2	1	2
Data suitability	*MEAN*	3,2	2,2	2,1	2,4	2,8	3,8	2	2,5	2,8	3	1,5	2
	MEDIAN	3	2	2	2,25	3	4	2	2,5	2	3	1,5	2
User guidance	*MEAN*	2,5	2,3	2,2	2,6	2,7	2,6	1,5	1,3	2,4	2,5	1,8	2,3
	MEDIAN	2,5	2	2	2,25	2,5	2	1	1	2	3	1,5	2
Understand-ability	*MEAN*	2,3	2,3	2,2	2,8	2,3	2,8	2	1,7	2,4	2,5	2,2	2,3
	MEDIAN	2	2	2	3	2	3	2	1	2	3	2	3
Data description/metadata	*MEAN*	3,8	3,2	1,8	3,2	4	4,6	1,8	4	4	4,5	1,7	2,7
	MEDIAN	4	3	1	3	4	5	1	4	4	4,5	1	3
Generation of a personalized view of information	*MEAN*	4,5	1,8	2	2,6	3	4,5	2,2	3,5	2,25	2,5	2,2	3,8
	MEDIAN	4,5	2	2	3	3	5	2	4	2	2,5	2	4
Quality of visualization	*MEAN*	3	2	2,6	2,5	2,3	3,8	2,2	3,1	2,3	2,5	2	2
	MEDIAN	3	2	2,75	2,5	2	3	2	3	3	2	2	2
3D functionlity	*YES OR NO*	YES	NO	NO	YES	NO	YES	NO	NO	NO	YES	NO	NO

Figure 11: Experts Evaluation Result [68]

According to the experts, the applications are bad in terms of "data description" criteria except for the three applications and the applications are good in terms of "user-guidance" and "quality of visualization" criteria.

2.7 Bikeability

Bikeability is a term used to describe and determine the level of interaction between the factors associated with bicycling in the area [69]. The bicycle lane conditions, trip distance, parking, and other factors have a direct impact on the bicycle trip. The bikeability becomes a frequent term in transport and urban planning. In some research studies, the bikeability term is used to evaluate the condition of streets for cyclists in an urban area [70].

However, evaluating the conditions of a street network is not enough to identify where improvements and development of a street network are needed. Lory et al. performed the evaluation of bikeability with the integration of quality of the street network and intersections [71].

The Bicycle Level of Service (BLOS) is a mostly used method to evaluate both the quality of the street network and intersections and it is explained in the Highway Capacity Manual (HCM) of the Transportation Research Board of US [72]. In BLOS, the parameters that are used to evaluate the quality of the streets are traffic volumes, speed of vehicles, and space for bicyclists and for intersection, the width of the street that is being intersected is used [73]. The BLOS method has some disadvantages, it does not include other factors such as the topography, built-in environment characteristics, and slope. The other drawback is that it is mainly developed for the US, and more research is required to examine whether it is useful and applicable in other countries context or not [74].

2.7.1 Measuring bikeability

The spatial analyses are used to measure bikeability by identifying the factors from the literature which have a direct influence on the people for bicycling. The next step is to assign weights to these factors according to their importance and determine the bikeability score for areas. The bikeability map is used to visualize the existing conditions for bicycling and help planners and decision-makers to increase and improve the bikeability. The following case-studies have developed the bikeability index by considering different factors.

Vancouver - Canada Bikeability Index:

Winters et al. developed a bikeability index by taking the public perspective for Vancouver, Canada to identify the high and low bikeability regions of the city by using the spatial data analysis [75]. To identify the parameters of the bikeability index, the qualitative data was collected from three different sources: Public opinion survey, travel behavior, and focus group.

The 1402 public participants took part in the opinion survey and the most important factors for the bikeability index were identified. The factors were traffic volume, bicycle facilities, the topography of the area, and the distance of the trip. In the survey, the participants were also asked about their preferred bicycle lane and a separate bicycle lane was selected by the public. In the travel behavior study, bicycle trips were analyzed to identify and understand the factors which influence the route selection for the trip. The goal of this study was to compare the actual route taken with the other possible shortest route between origin and destination location of the trip. The bicycle facilities, connectivity of the streets, the topography of the area, and area land-use were the main factors. In Focus groups, the bicyclists were divided into four groups according to their bicycling activities. The bicycle facilities factor was selected from the focus groups.

Winter et al. identified five main factors for the development of the bikeability index: bicycle facilities, connectivity of the streets, bicycle route separation, topography, and land-use of the area [75]. Each factor was scored on a scale of 1 to 10 and combine all factors to produce a composite bikeability index map. The figure-13 shows the bikeability index map for the Vancouver region, the green color shows the areas where the bicycling conditions are good and the red color shows where bicycling conditions need improvements.

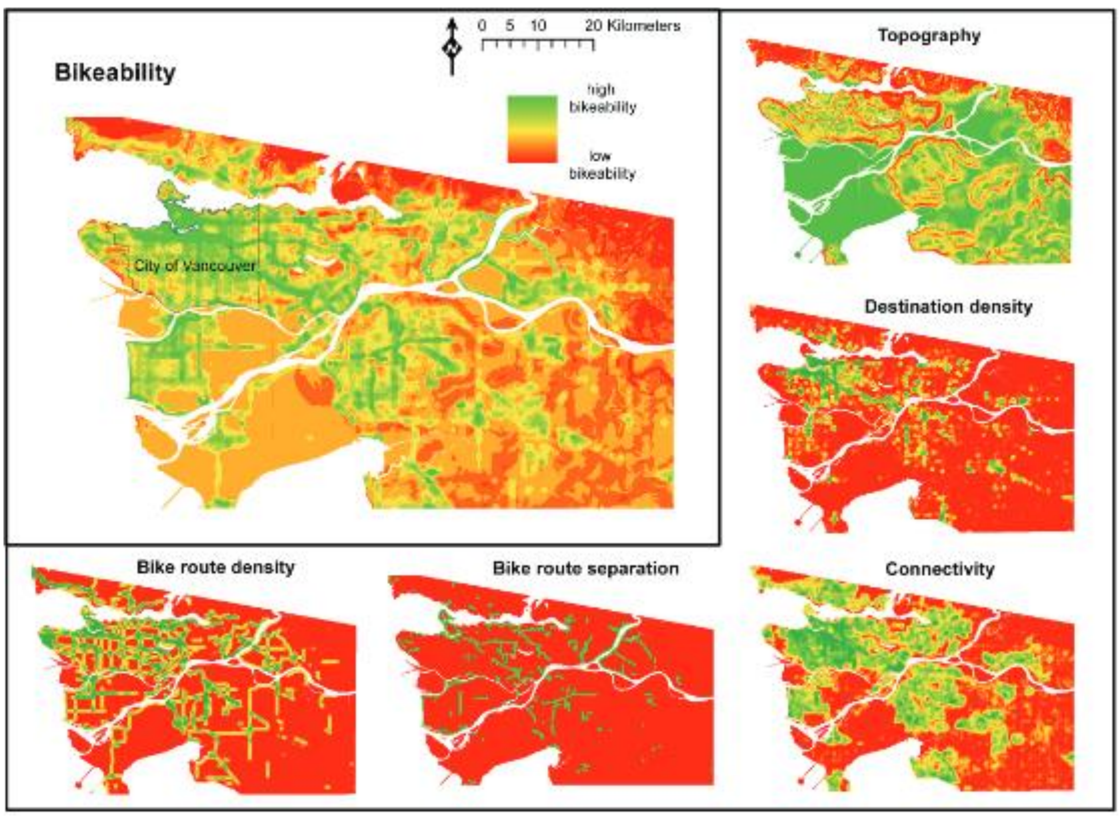


Figure 12: Bikeability maps for Vancouver [75]

The one limitation of this study is that they do not consider other important factors such as population density, bicycle parking facilities, and traffic safety that also influence the use of a bicycle, and evaluation of bicycling in high and low bikeability regions are needed.

Austin – US Bikeability Index:
In a similar study, the bikeability index and map were created for Austin city of Texas state in the US [76]. In this study, the factors were mapped and scored to identify the current bikeability of the city. The bikeability index consists of bicycle facilities, street network connectivity, slope, land use, and barriers. These factors were weighted according to their impact on the bikeability of the city and produce a composite map for the current bikeability in the city. The values of the bikeability index range from 0 to 100.

The potential bikeability map was also created by considering the suggestions from the Bicycle Master Plan of Austin 2014 which is about to increase the bicycle facilities and network and improve the existing conditions. This bikeability index also does not consider the population density, traffic safety measures, and bicycle parking factors. The figure-14 shows the current and potential bikeability in Austin city.

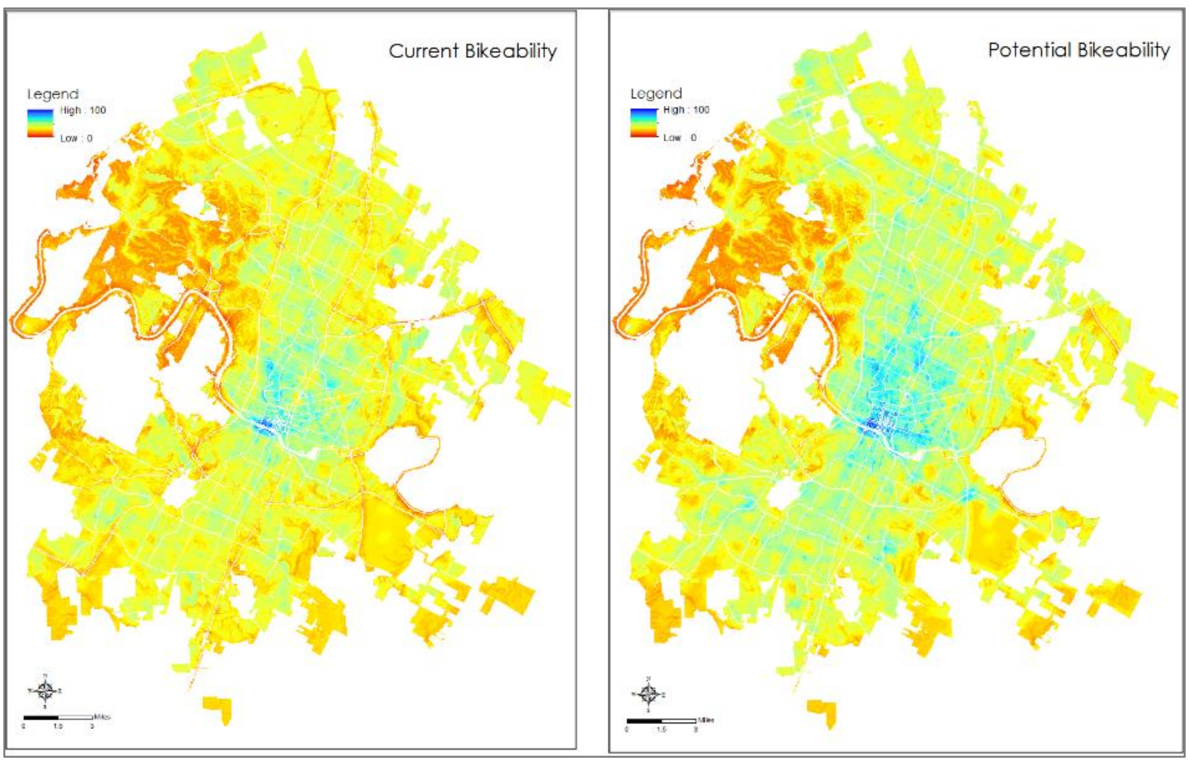


Figure 13: Current & Potential Bikeability maps for Austin [76]

Graz - Austria Bikeability Index:
In this research study, the bikeability index was developed and measured the bikeability based on the built-environment factors of the Graz city in Austria [70]. The bikeability map was produced to examine the current bikeability in the city.

In this index, 278 bicycle trips of 113 participants were used to identify the aspects of the built environment and distance difference by comparing the actual route taken by participants and the possible shortest route between the start and end location of the trip. The bikeability index values were classified from 1 to 10 where 10 indicates the high bikeability areas and 1 indicates low bikeability areas. The one limitation of this bikeability index is the use of "Green & Aquatic areas" as a factor. Because the high bikeability areas are found in the center of the city while most parts of green & aquatic areas are found at the boundary of the city which is totally different. The figure-15 shows the factors used and the final bikeability map of Graz city.

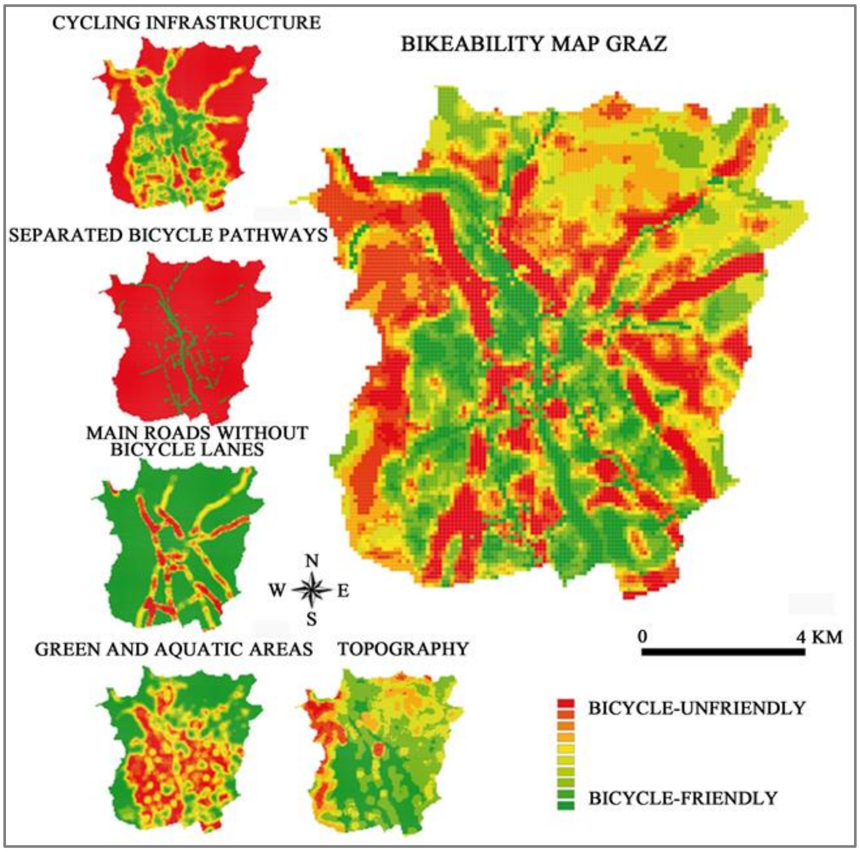


Figure 14: Factors & Bikeability Map of Graz City [70]

3 WPPGIS APPLICATIONS - TECHNOLOGY OVERVIEW

As in the previous chapter, it is found that the traditional methods of public participation are changing towards the e-participation. The internet and web development are also changing the way to access and use spatial data. The webGIS applications are becoming more useful in the context of public participation for spatial planning and decision-making processes without any restriction of location and time to public participants. In this chapter, we review the PPGIS and internet technologies that help in the development of web-based PPGIS applications. The data collection & description, application design, development, and implementation is also explained.

Traditionally, the GIS system is used to handle the input, management & processing, analysis, and visualization of the data. These tasks can be implemented in the web-based applications as shown in the table-4;

GIS Tasks	Web Component
Input	Client/Server
Data Management	Database (DBMS)
Data Analysis	Geospatial Libraries
Visualization	Client (user interface)

Table 4: GIS Tasks & their Related Web-Components

3.1 Development Cycle of WebGIS Application

The development of the webGIS application is easy and many approaches have been suggested for successful implementation [78,82]. The development of a web-based GIS application is an iterative process;

1. **Understand and specify the context of the use:** In the first stage of the webGIS application development, the purpose and the requirement of the application will be determined. In this stage, the expectations of the client user from the application are considered. The required data and list of functions needed for the application are also determined.

2. **Specify the application requirements:** In this stage, the conceptual model of the application will be designed. It provides the view and main aspects of the overall application. It helps to understand how different components of the application are integrated and working such as how the data will be delivered to the client? The architecture of the webGIS application is also designed in this stage. At this point, the technologies will be selected (such as which scripting

language will be used for client-side? which map server will be used?) for the successful implementation of the webGIS application.

3. **Designing and developing the application:** This activity includes designing and developing the application based on the context of use and user requirement. In this stage, the development of the webGIS application is started. The main objective of this stage is to integrate the different components, so the application runs smoothly and to initiate different functions of the applications for the users.

4. **Evaluation of the developed application:** Once the application is developed, the assessment of the application will be performed to find out whether the application meets the user requirement or not.

The figure-16 shows the iterative process of web-based GIS application development.

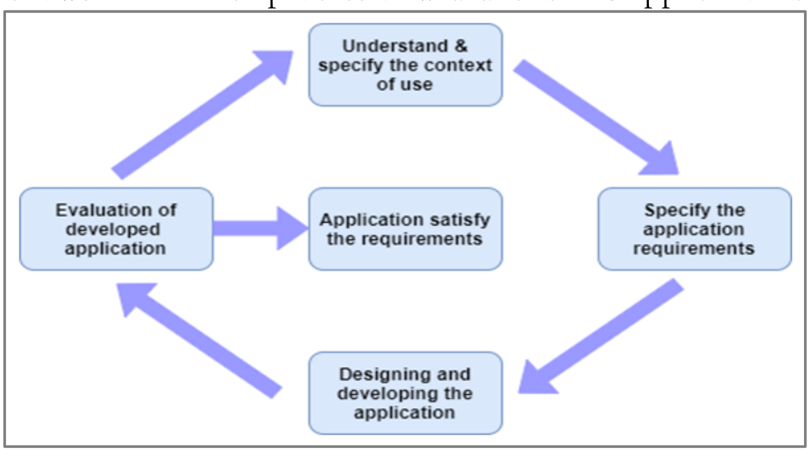


Figure 15: Iterative Process of Web-based GIS Application Development

3.2 Web-based PPGIS Application Architecture

Peng et al. defined the WebGIS term as "Network-based geographic information services that can utilize wired or wireless Internet protocols to access geographic information, spatial analysis tools, and GIS Web services" [77]. They explained that most of the webGIS applications are based on the client-server architecture system in which functions (retrieval of spatial data, display and explore data, etc.) are allocated between server and client. In a client-server system approach, the web browser acts as a client and the server part consist of a web server, map server, GIS component, and databases. The general architecture of the client-server webGIS application is shown in the figure-17.

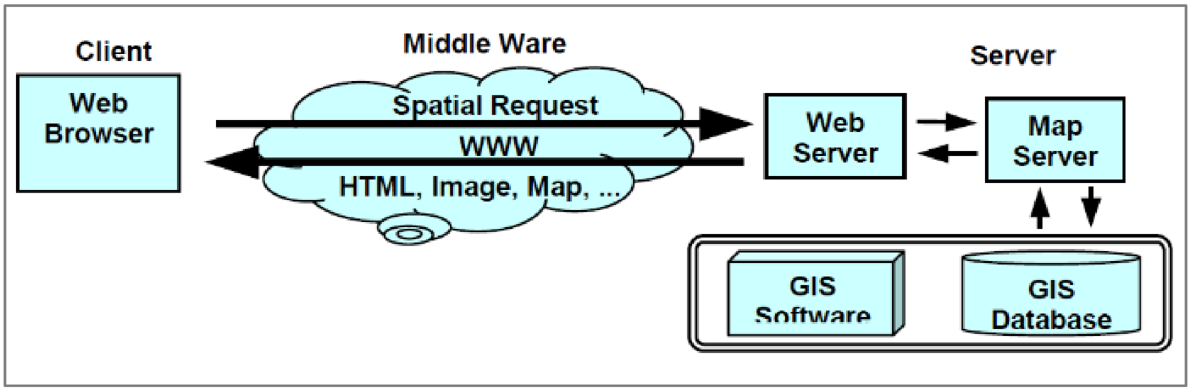


Figure 16: Typical WebGIS Model for Application Development [82]

The client sends the request to the server to retrieve the information and in response, the server sends back the appropriate information to the client. The middleware is used to provide communication between the client and the server-side. The multi-tier architecture is used in the client-server model where geoprocessing of GIS component is distributed into a client and server-side tasks respectively [78]. The multi-tier architecture helps to support the maintenance and modification of the application without affecting the user's (client) computer performance [79-80].

Two types of the client-server approach are used to design and develop web-based PPGIS applications and determine where the processing of data occurs: Thin-client (server-side processing) and Thick client (client-side processing) [81]. In the thin-client approach, data is stored and processed at the server and the results are sent to the client machine while in the thick-client approach, the data processing is performed on the client machine system. The figure-18 shows the distribution of processing between different thin-client and thick-client;

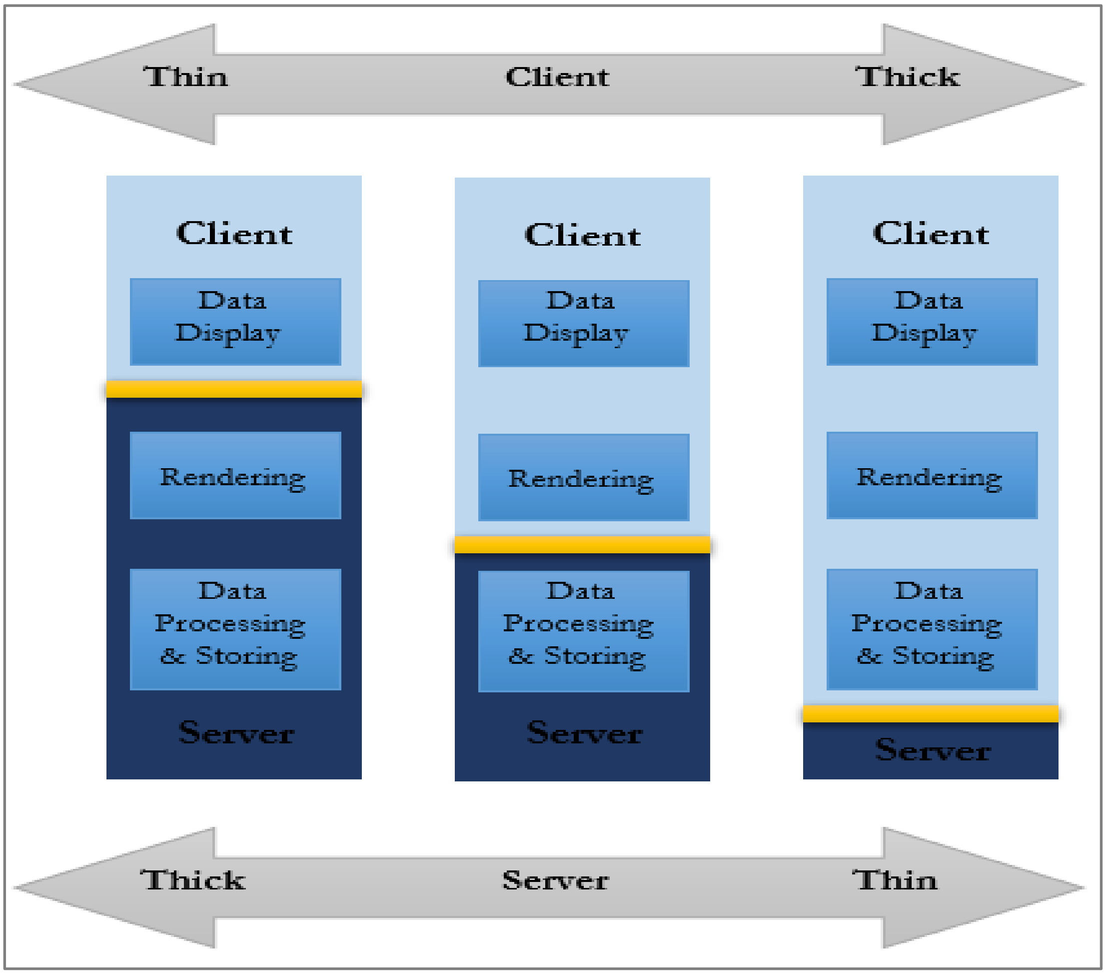


Figure 17: Distribution of Processing between Thin-Client and Thick-Client Architecture

3.2.1 Thin-Client Applications (Server-Side Architecture)

In thin-client applications, the client has only a user-interface on their computer to communicate with the server and visualize the data. Most of the tasks are processed at the server end therefore the server-side computers are powerful to manage and process the data than the client [78]. For the webGIS applications that are based on the thin-client architecture, the client does not need to install any additional software to run this application. The application can be accessed and used only by a web browser from any place [82]. The user can only request, access, and view the data in thin-client applications.

As data processing is not dependent on the client machine, the application can be revised or update the functionality of the application easily at the server-side. The speed of the application performance is limited due to the task processing at the server-side and depend on the internet network. The figure-19 shows the processing approach for thin-client applications.

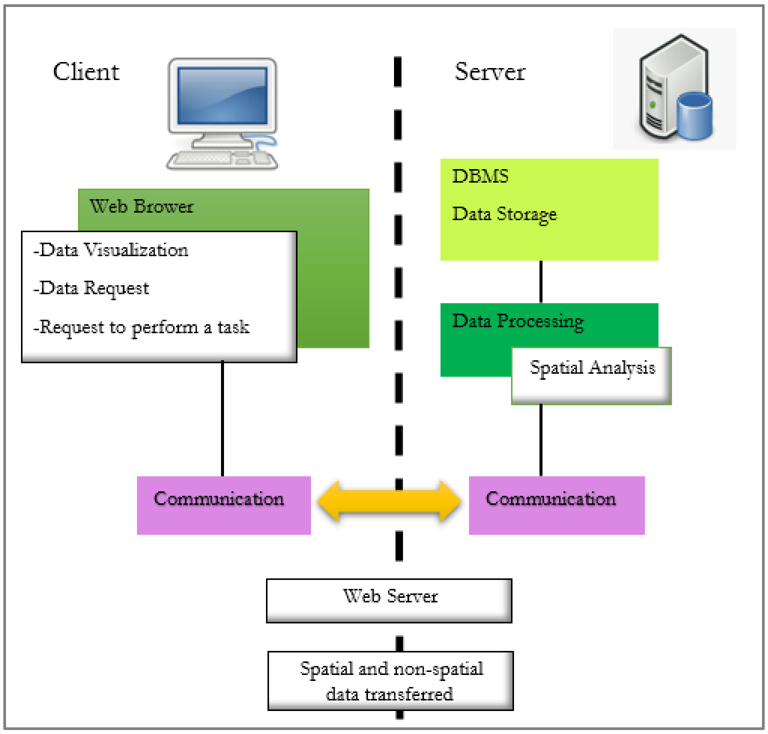


Figure 18: Thin-Client Applications Processing Approach

3.2.2 Thick-Client Applications (Client-Side Architecture)

In a thick-client application, most of the processing is carried out at the client-side with a user-interface. There is very less involvement of the server-side and the data is processed locally. The client also needs additional software at the client-side to run this application. The figure-20 shows the processing approach for thick-client applications.

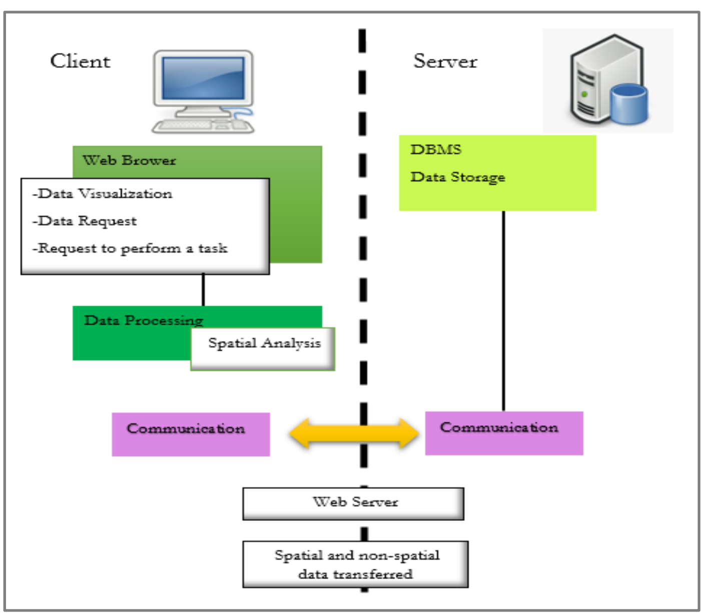


Figure 19: Thick-Client Applications Processing Approach

3.2.3 3-Tier Architecture of Client-Server Application

The 3-tier architecture based on a thin-client approach is used to design and develop many webGIS applications as it provides easy maintenance for the data layers and applications [83]. It allows the easy separation of the presentation tier (client user-interface) from the application tier (server components) and the database tier (data storage source) [85, 86]. The open-source technologies are used to develop webGIS applications based on 3-tier architecture to provide the solutions and achieve user requirements. The figure-21 shows the architecture of webGIS applications based on a 3-tier.

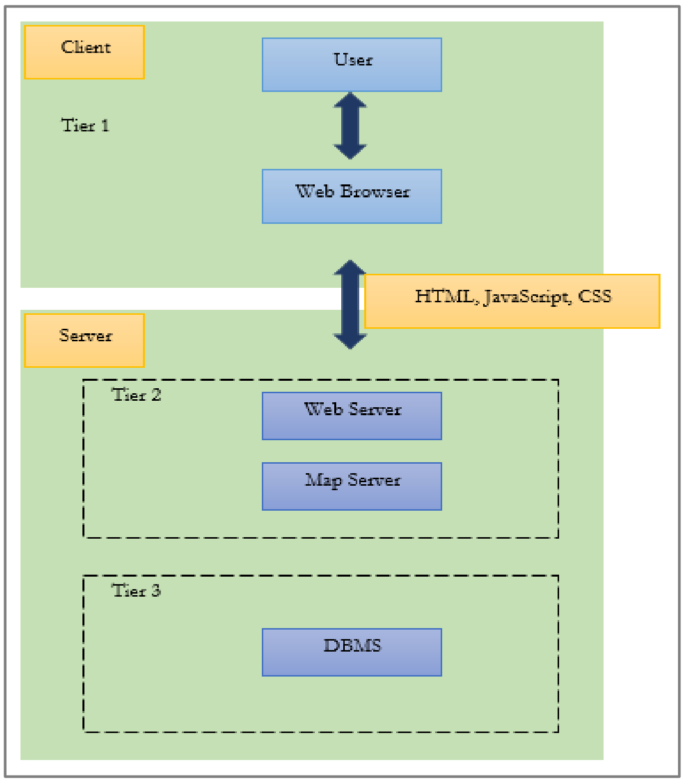


Figure 20: WebGIS Application based on 3-tier Client-Server Architecture

The server-side approach is used as it does not require any additional complex software and plug-ins to install on the client machine and affects the usability of the application. Typically, the server-side contains the web server, map server, and databases that provide the geoprocessing services and storage place to store spatial & non-spatial data. The web server provides the communication and transfers the data between the map server and the client-side machine. The user-interface at the client-side allows the user to access, view, request, and explore the spatial and non-spatial data. The figure-22 shows the example of the workflow of the communication between the components of the server and client-side.

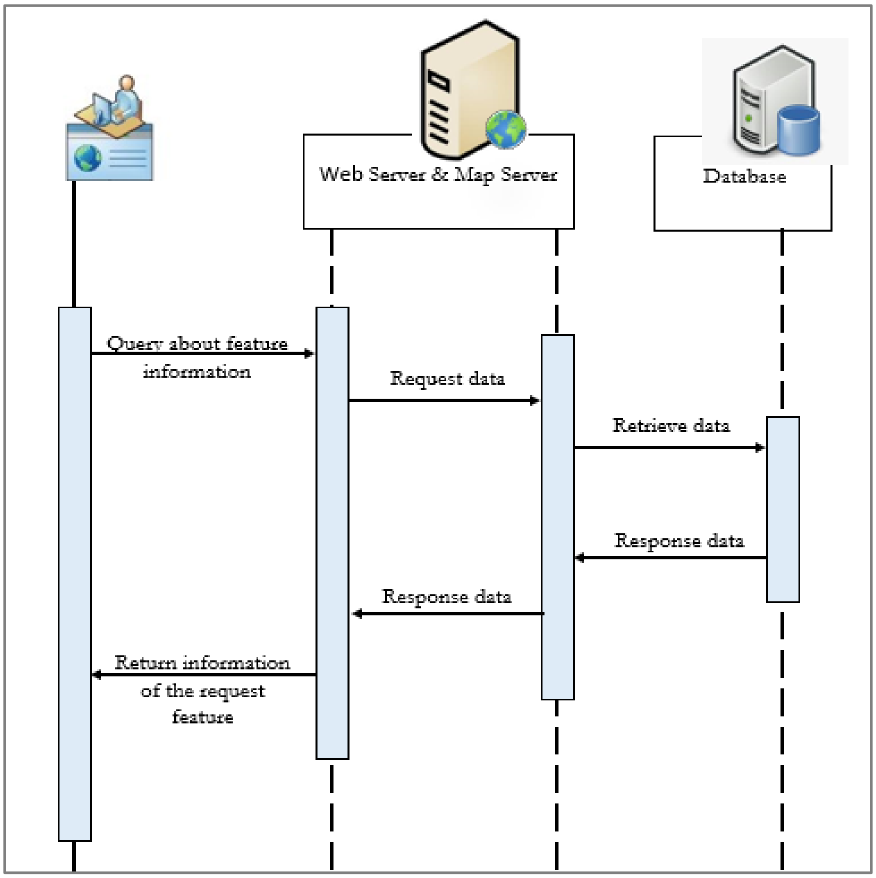


Figure 21: Communication Process between Client & Server Components upon User Request

The following section will explain the open-source technologies for different components used in the 3-tier architecture;

3.2.4 Server-Side Components

Database (Spatial Database):

The Open Geospatial Consortium (OGC) has contributed a lot to the development of spatial databases that can manage and store the spatial and non-spatial data in the database management system (DBMS) [84].

PostgreSQL is an open-source object-relational database management system (ORDBMS) with open access protocols [87]. It allows to use and develop new functions by using different scripting languages, provides better data protection, and works on all operating systems. PostGIS is an open-source spatial database, an extension to the OGC PostgreSQL database [88]. The spatial component is added in the PostgreSQL database to store, manage, and query the spatial and non-spatial data and used in many GIS applications [89]. It provides many reliable and fast built-in functions for the processing of spatial data. The main advantage of using the PostGIS database with the combination of GeoServer is that it allows storing the spatial data by using the OGC web-services. The server-side programming languages such as Python and PHP also provides functions to connect the PostGIS database and perform queries.

3.2.5 GeoServer

GeoServer is an open-source Java-based server-side software used to share, analyze, and edit spatial data from different database sources [90]. GeoServer helps to retrieve and display the spatial data at client user-interface from a database by using the standard OGC web services. GeoServer can be used with GeoWebCache to cache data from various sources and help to transfer the map tiles quickly. The figure-23 shows the services that are supported by GeoServer.

Figure 22: Functions Supported by GeoServer [91]

It contains many standards of OGC such as Web Map Service (WMS), Web Feature Service (WFS), Web Processing Service (WPS), and Geography Markup Language (GML) [92].

Geography Markup Language (GML): It is an eXtensible Markup language (XML) developed by OGC to encode the spatial features. It is used for the transaction of spatial data on the internet.

Web Map Service (WMS): It allows the user to request and visualize the map images via a web browser from different data sources. The response map tiles (in the format of JPG, JPEG, or PNG, etc.) are displayed at the user interface of the client.

Web Feature Service (WFS): It allows the user to request, query, update, or remove the spatial data on the map through the web browsers. The response result is encoded in GML language.

Web Processing Service (WPS): It allows the user to perform geoprocessing tasks such as buffer operation on the spatial data on servers.

3.2.6 Libraries for Client-side Development

For the development of client-side user-interface, many scripting languages and open-source libraries are available.

HyperText Markup Language (HTML): The HTML is used to design and develop webpages. The webpage contains the elements and attributes of HTML to define the content of the webpage [106]. The webpage contains the page title, metadata, and links to other files and libraries that are used in web application development. The HTML files are ASCII-files, and they can be created or edited in any normal text editor software. The standard extension of HTML files us .html [107].

Cascading Style Sheet (CSS): It is developed by the World Wide Web Consortium (W3C) and responsible for styling the content of the webpages [108]. The CSS is used to make webpages more attractive and defines how the elements of HTML will be displayed. JavaScript is usually used with the integration of CSS to provide a more responsive application interface. The standard extension of CSS files is .css.

JavaScript (JS): It is an object-oriented programming language and used to define the behavior of webpages [109]. The JS files can be executed inside the web browsers on the client-side. As web browsers mostly contain a JavaScript interpreter to understand and execute the code. It is also referred to as "Front-End Development." Similarly, JS files can also be executed on the server-side by using a framework of JS called node.js [110]. This type of execution is called "Back-End Development." The standard extension of the JavaScript files is .js.

ExtJS: It is a framework of JavaScript used for developing client-side applications. It provides the elements to develop the rich Graphical User-Interface (GUI) for web applications [94].

GeoExt: It is an open-source library and extended version of ExtJS that uses the basic components of ExtJS to create web-mapping applications. The webGIS applications are developed by the integration of Leaflet with ExtJS and GeoExt libraries to allow the user to visualize, edit, and share the spatial data [95].

GeoJSON: The GeoJSON is a standard of spatial data format to represent spatial objects with their nonspatial attributes [121]. The GeoJSON is a more useful spatial data format as compared to the larger size of the Keyhole Markup Language (KML) format. The GeoJSON data is smaller in size, simple to understand and edit, and easily manipulated by JavaScript. The figure-24 shows the format of a GeoJSON.

```
{
  "type": "Feature",
  "geometry": {
    "type": "Point",
    "coordinates": [125.6, 10.1]
  },
  "properties": {
    "name": "Dinagat Islands"
  }
}
```

Figure 23: Format of GeoJSON File [121]

jQuery: It is a light-weight and fast JavaScript library that is used for event handling and manipulation of HTML & CSS files [111]. The extensibility and versatility of the jQuery library make the use of JS easier in web development with "write less, do more" in mind. The figure-25 shows how to handle the user event when it is a trigger.

```
var hiddenBox = $( "#banner-message" );
$( "#button-container button" ).on( "click", function( event ) {
  hiddenBox.show();
});
```

Figure 24: Handle User Event in jQuery [111]

Web Maps API:
The framework of Application Programming Interface (API) is used to write a program. It contains different classes and functions used to perform different tasks. The web map APIs allow the developers to add maps and display or edit a data layer on maps by calling the functions.

Google Maps API: The Google Maps API help to request maps from Google paltform and display them on the web pages [122]. The API provides four basic types of maps (Satellite, Terrain, Streetmap, and Hybrid) to the user. The Google Map API also supports the KML geospatial data format to display the data on the map. The one disadvantage of the free Google Maps API key is that it cannot handle more than 100000 requests per day [123].

OpenStreetMap API: The model of Open StreetMap is based on the Volunteered Geographic Information (VGI) [124]. It is an open-source platform and developed by thousands of contributors. The OpenStreetMap gives free access to the data under their open license. The code part of OpenStreetMap API is more complicated and a bit longer as compared to other web maps APIs.

Mapbox API: The Mapbox is an open-source JS library to provide the interactivity and control functionality of the map. It also provides functions to change the style of custom web maps. The designing and developing a web application with Mapbox is simple [125].

Leaflet API: The leaflet is an open-source and light-weight JS library to provide interactive web map facilities to the web browser [113]. The leaflet library is designed with the concept of usability, and simplicity so it provides better performance. The leaflet library has built-in functions to control the maps and overlay raster and vector spatial data. It also supports the standards of OGC such as WMS, WFS, and WCS. The leaflet library has many plugins available that allow the developers to integrate them with the leaflet library for their web application. The leaflet API also supports the integration of plugins with this library.

4 Bikeability Index Methodology & Factor Maps

4.1 Factors used to Measure Bikeability

In this chapter, the importance of the bikeability factors will be explained that are identified from the scientific literature. These factors will be used in this study to measure the current bikeability of the study area. The bikeability factor-based model by Loidl et.al will be used as a base for measuring the bikeability and developing a bikeability index [96]. According to the importance of each factor, a score value between a range of 1 to 10 will be given and compared with other factors. The score value of 1 means a strong negative impact on bikeability and the score value of 10 means a strong positive impact on bikeability.

4.1.1 Bicycle Infrastructure

The bicycle infrastructure is an important component in measuring the bikeability of an area. The bicycle infrastructure consists of different bicycle lanes such as separate bicycle lanes, buffered bicycle lanes, neighborhood bicycle lanes, shared lanes, etc. This infrastructure provides space and safety to bicyclists while bicycling in the area [74,75,97,98]. To increase bicycling, the bicyclists need such bicycle infrastructure in the area that meets their preferences.

In the university campus of Mayland, a survey-based assessment discovered that the public did not feel safe during bicycling on streets shared with motor vehicles and due to lack of bicycle infrastructure there was less bicycling in the university [99]. The research by Krenn et al. examined how the presence of more bicycle infrastructure increases the number of bicyclists and improves the bikeability of the city [70]. The study by Stefansdottir identified that the presence of traffic has a negative impact on bicyclists [100]. The bicyclist preferred completely separate bicycle lanes from the motor traffic lanes to feel safe during bicycling.

4.1.2 Topography (Slope)

The slope of the area directly impacts the level of comfort of bicyclists while bicycling. For example, when bicycling towards a high slope, the bicyclist needs extra energy and effort. In previous research studies, they include hilliness as a factor to measure the bikeability [75,98]. They discovered that the high hilliness had a strong negative influence on public willingness to bicycle. Both Stefansdottir and Krenn et. al identified that low slopes had a positive impact and high slopes areas had a negative impact on bicycling in their research studies [70,100].

The Titze et al. identified a positive correlation between bicycle usage and slope in their research study. But this bicycle usage was only for recreational purposes [101]. Nowadays for many bicyclists, high slope areas for bicycling are becoming less problem because electric bicycles solve this issue.

4.1.3 Street Network

The street network or connectivity of the streets in the area is also an important factor that has an influence on the bikeability. The type of streets also have an impact on bicycling such as highways, municipal streets, or neighborhood streets and they have different speed limits and volume of traffic. For example, bicyclists preferred residential or neighborhood streets due to their safety conditions and avoid main local streets that have a high volume of traffic and traveling speeds [75,100].

4.1.4 Bicycle Parking

The bicyclist prefers routes with bicycle parking facilities on the side of the street [98]. The previous research studies had investigated how the presence of bicycle parking facilities increases the bikeability of the city [99,102]. The presence of secure bicycle parking at the train stations and bus stops also motivates people to use bicycles instead of motor vehicles to reach there and parked their bicycles for a short-term time.

The national household travel survey in 2017/2018 in U.S.A and Germany shows that bicycles are parked for 23 hours per day [103]. So, bicycle parking is an important infrastructure for bicycling in the city. Bicycle parking not only provides shelter for bicycles but also protects them from theft and weather conditions.

4.1.5 Bicycle Safety

The safety of bicyclists is a very important factor while improving and increasing the bikeability in the area. The bicycle safety can be determined from the past happened traffic accidents that involved bicyclists. In fact, in motor vehicle dominant areas, the bicyclists do not feel safe and comfortable during bicycling and even it is more stronger when they have to share the street with motor traffic. As in previous research studies, the bicycle safety factor was not included during the measuring of bikeability [75,76].

4.1.6 Residential Density

The residential density is another important factor that has also an impact on bikeability. The residential density measures the number of people per square kilometer or square miles of area. The previous research study identified that the usage of bicycles is directly associated with factors such as residential densities, land use, and income of peoples in the area [104]. If the areas of high residential densities have low bikeability that indicates the area has poor bicycle infrastructure and facilities and people are not willing for bicycle usage. Similarly, in previous research studies, the residential density factor was not included during the measuring of bikeability [75,76].

4.2 Bikeability Index Methodology

In this section, the methodology for developing the bikeability index that includes the built environment and other factors for measuring the bikeability of the area will be explained. The multi-criteria spatial analysis will be used to measure bikeability because of various factors that impact the usage of bicycles and no individual factor has a major impact. The factors used in the bikeability index are bicycle infrastructure, safety, parking facilities, topography (slope), and residential densities.

The identified factors of bikeability have a different level of importance from each other and influence people's willingness, safety, and level of comfort. For example, when a bicyclist has to select a trip route, he might give more importance to the bicycle infrastructure than any other factor. So, there is a need to create a bikeability index to determine the impact of various factors.

A bikeability index is a useful tool that allows the planning and decision-making authority to increase the usage of bicycles and improve the bikeability conditions by identifying the low bikeability areas from the bikeability map. The bikeability index is based on the spatial data to provide the bicycling conditions of a particular location.

The ESRI ArcGIS Pro software is used to perform all the data preprocessing and other geoprocessing functions. The factor maps are produced from the collected and then classified on a scale from 1 to 10. The 10-score value indicates a positive impact and the 0-score value indicates a negative impact on bikeability. After that, the factors are weighted and combine to produce a composite bikeability map by using the "Weighted Overlay" function in the ArcGIS Pro software. The bikeability map is used to investigate the current bikeability condition in the area.

The data used in this study during measuring bikeability and developing web-based PPGIS is obtained from an open data portal of Chicago city [129]. The table-5 shows the data obtained from Chicago data portal.

Dataset Name	URL	Dataset Type
Road Network	Chicago City Data Portal https://data.cityofchicago.org/Transportation/Street-Center-Lines/6imu-meau	Polyline
City Boundary	https://data.cityofchicago.org/Facilities-Geographic-Boundaries/Boundaries-City/ewy2-6yfk	Polygon
Bicycle Stations	https://data.cityofchicago.org/Transportation/Divvy-Bicycle-Stations-In-Service/67g3-8ig8	Point
Bicycle Routes	https://data.cityofchicago.org/Transportation/Bike-Routes-Deprecated-February-2020-/auur-f9g5	Polyline
Bicycle Parking Racks	https://data.cityofchicago.org/Transportation/Bike-Racks/cbyb-69xx	Point
Educational Centers	https://data.cityofchicago.org/Education/Chicago-Public-Schools-School-Locations-SY1718/4g38-vs8v	Point
Slope	https://data.cityofchicago.org/Buildings/Elevation-Benchmarks-Map-By-Elevation-Range/4x56-dvnp	Point
Bicycle	https://data.cityofchicago.org/Transportation/Traffic-	Point

Accidents	Crashes-Vehicles/68nd-jvt3	
Community Zones	https://data.cityofchicago.org/Facilities-Geographic-Boundaries/Boundaries-Community-Areas-current-/cauq-8yn6	Polygon
Census Data	https://data.cityofchicago.org/Facilities-Geographic-Boundaries/Boundaries-Census-Blocks-2010/mfzt-js4n	Polygon

Table 5: Data used for Application Development

4.2.1 Spatial Analysis of Bikeability Factors

In this section, the obtained results of the spatial analysis performed on the factors of bikeability index with the support of ArcGIS Pro software are discussed.

Residential Density:

The residential density is calculated by the number of population from the census data in a particular area. The residential density is calculated from the equation-1;

$$\textbf{Residential Density} = \frac{\textbf{Number of people in specific area}}{\textbf{Area }(\textbf{Km}^2)\textbf{ of the specific area}}$$

Equation 1: Residential Density Formula [105]

The residential density values are grouped into 10 different classes by using the "Natural Breaks" method. The class 1 indicates the low-density areas (less populated areas) and class 10 indicates the high-density areas (high populated areas). The figure-26 shows the map of residential density.

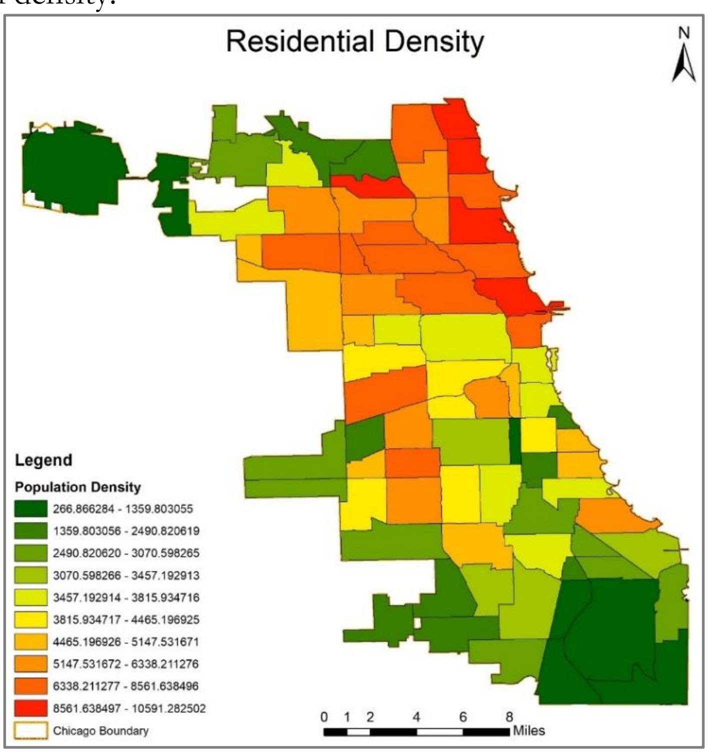


Figure 25: Residential Density Map

Topography (Slope):
The topography map is produced based on the elevation values that are measured at the different locations of the city by the city administration. The higher slope areas are given less score value (1) because they are less suitable for bicycle usage and less slope areas are assigned a high score value (10).

Bicycle Safety:
The bicycle safety map is generated based on the previous bicycle accident location between 2017 to 2020 in Chicago city. The areas with a high number of bicycle accidents are assigned a low score value and areas with no bicycle accidents are assigned a high score value. The figure-27 shows the map of bicycle accidents density map.

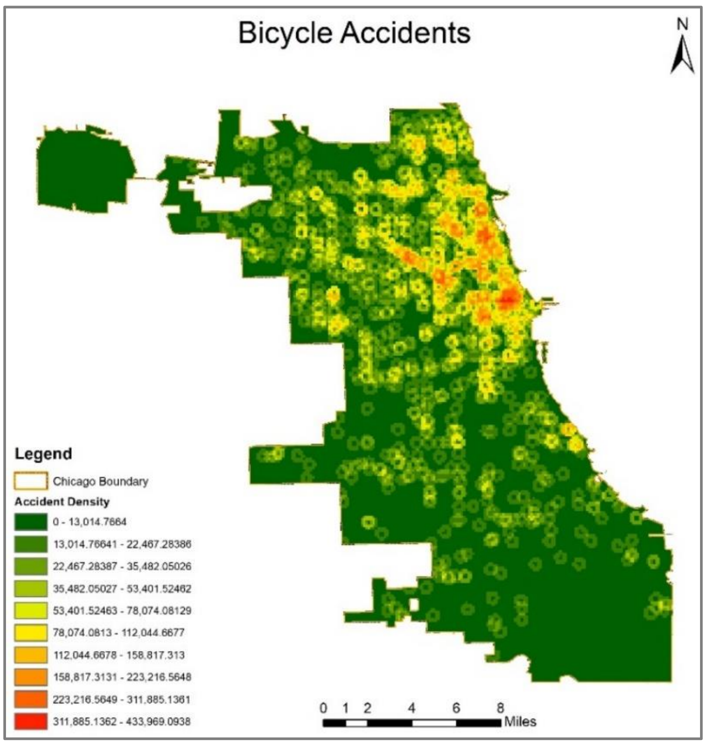


Figure 26: Bicycle Safety Map

Bicycle Parking Facilities:
The bicycle parking facilities map is generated based on the number of provided parking facilities in the area. The areas with a high number of bicycle parking facilities are assigned a high score value and areas with no bicycle parking facilities are assigned a low score value. The figure-28 shows the map of bicycle parking facilities.

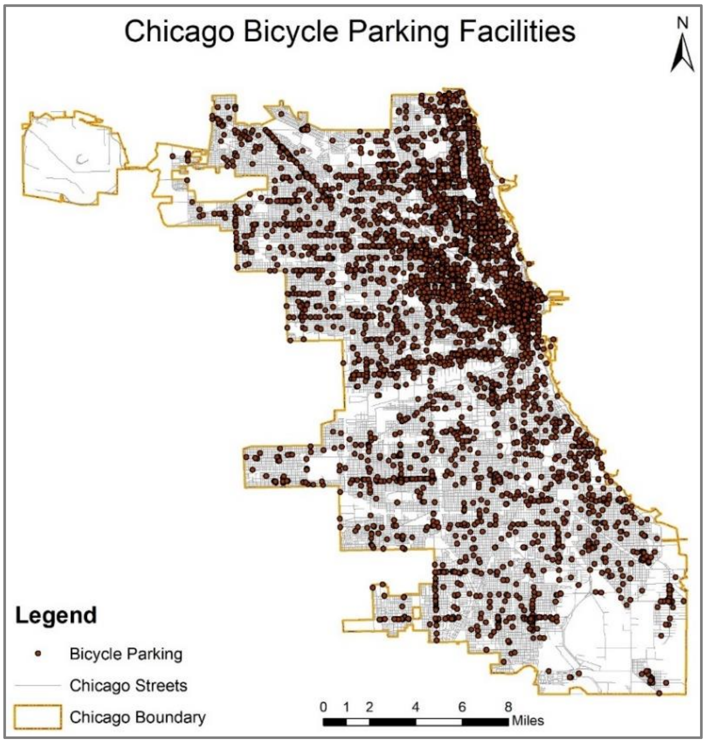


Figure 27: Bicycle Parking Facilities

Bicycle Infrastructure:

The bicycle infrastructure map is produced by using the buffer tool on the bicycle infrastructure and other general streets of the area. The figure-29 shows the different types of bicycle infrastructure.

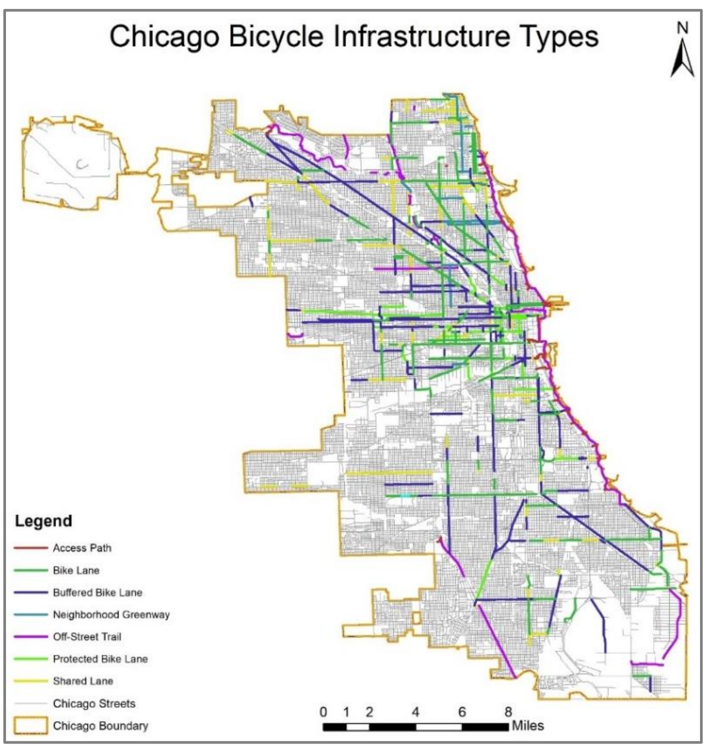


Figure 28: Bicycle Infrastructure Types

To produce a final composite bikeability map, the weights are assigned to each factor based on their level of impact on the bikeability. In the current bikeability map, all the factors are included. The final result of the bikeability index is classified into 4 classes; high bikeability areas, moderate bikeability areas, low bikeability areas, and no bikeability areas. The high and moderate bikeability areas are represented in a red color gradient and moderate and least bikeability areas are represented in a blue color gradient. The figure-30 shows the overall conditions of bikeability across Chicago city.

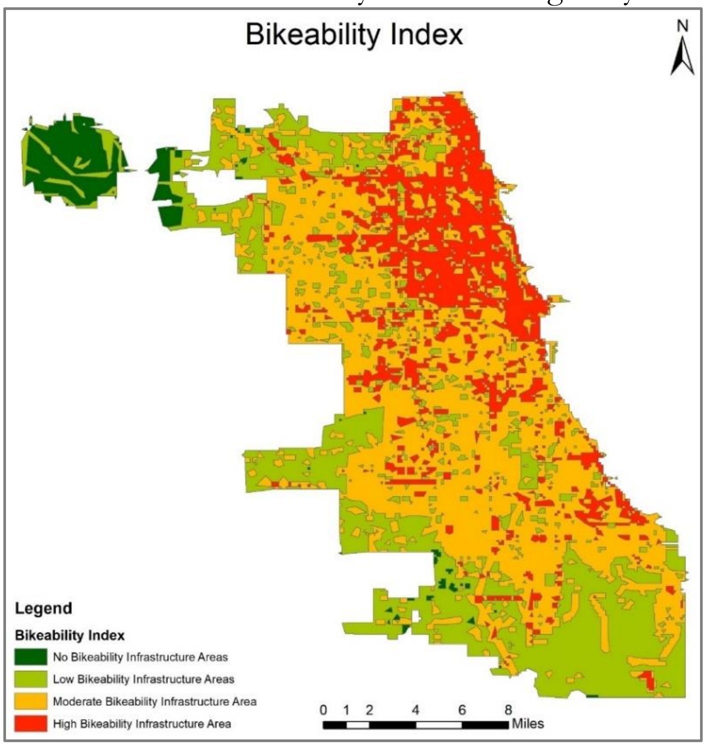


Figure 29: BIkeability Index Map

The following graph shows the area percentage contained by 4 different classes of bikeability index.

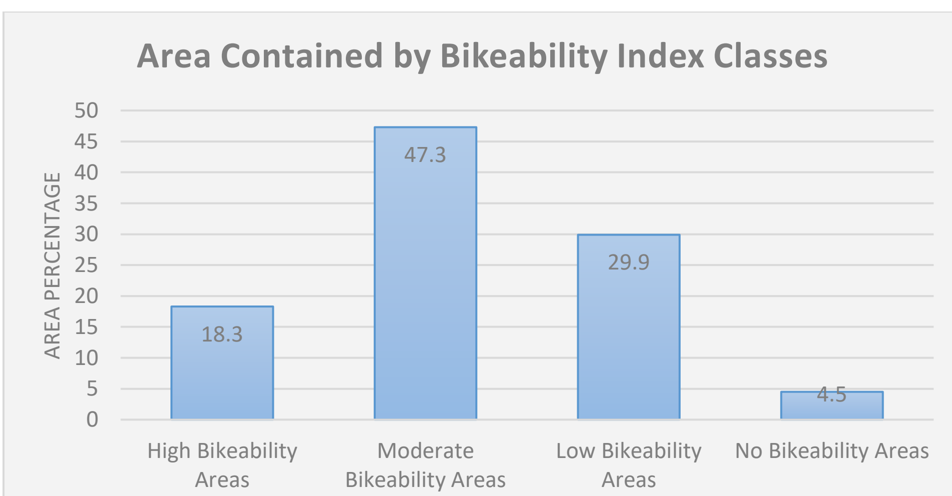


Figure 30: Area Contained by 4 classes of Bikeability Index.

5 Web-based PPGIS Application Implementation

The main objective of this study is to design and implement a web-based PPGIS application is to improve and support public participation during urban planning and decision-making processes. It mainly depends on the understanding of public participation concepts in urban planning (such as the level of public participation and existing public participation methods) and identifying the functional requirements for the application from the existing PPGIS applications (discussed in Chapter-2).

5.1 Web-based PPGIS Application Architecture

The web-based PPGIS application is developed on the server-client architecture. In this architecture, all the data processing and storage are performed on the server-side. The users at the client-side can visualize the data, perform the task, and send the request to add new data or modify or remove the current data on the map to the server. The server receives and processes the client request and updates the application in response. The figure-32 shows the web-based application architecture.

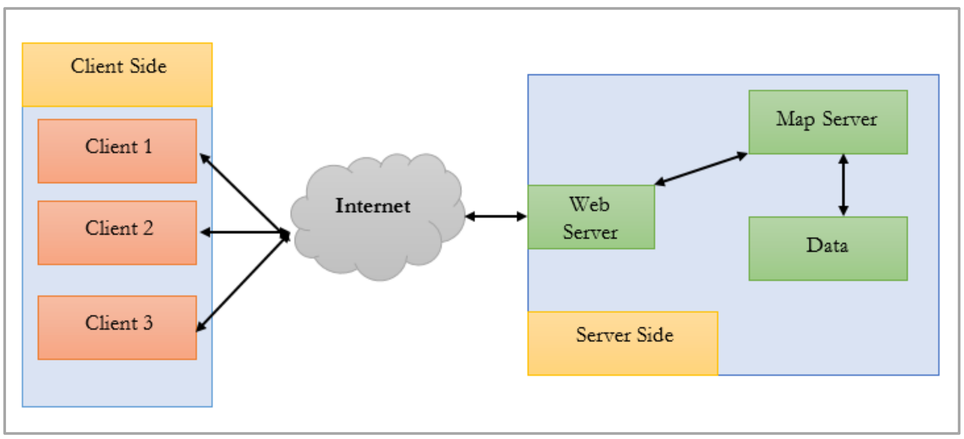


Figure 31: Web-based PPGIS Application Architecture

The client-side is developed by using HyperText Markup Language (HTML), Cascading Style Sheet (CSS), and JavaScript web development scripting languages. The client-side runs inside the web browser to connect the server via the internet and allows the user to use the application without any installation of additional software, and specific libraries or plugins. The user at the client-side views and interact with the HTML documents. The JavaScript files contain functions used to manage user events, send user requests to the server, and change the HTML document structure & appearance. These files are executed at the end of the client's web browser.

The server-side consists of a web server, map server, and a database. The server helps to provide the data to the user, processes the client requests through the Hypertext Transfer Protocol (HTTP). The MapServer helps to support the display of maps and process the client queries. The databases are used to store spatial and non-spatial data. For example, when a user clicks on the checkbox to visualize a specific data layer on the map, the client request sends to the server. The server processes the request and displays that specific data layer on the map in response. The figure-33 shows the workflow of the proposed web-based PPGIS application.

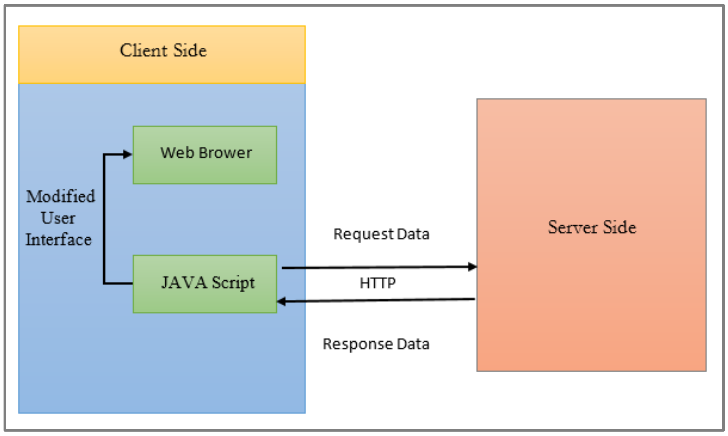


Figure 32: Workflow of Web-based PPGIS Application

The rendering process is used on both the server-side and client-side of the application to improve the application load time if there is a minimum latency of network latency and improve the server-side processing. The map and its related data are rendered on the client-side only. The JavaScript code is used to process the client request and provides communication between client-side and server-side. The open-source technologies are used to develop a web application that provides benefits such as no vendor lock, cost-effectiveness, and flexibility.

5.2 Web-based PPIS Application Implementation

5.2.1 Technical Requirements

The web-based PPGIS application has been developed by using the following open-source technologies, libraries, Application Programming Interface (API), and plugins.

HyperText Markup Language (HTML): HTML is used to develop the web page content by using different tags. The syntax of HTML is very simple, and it is easy to understand and use. The web browsers deal with the content of web pages. The HTML5 version is used in this study to develop webpages as it is the latest version of HTML [107].

Cascading Style Sheet (CSS): The CSS files are used to explain the rendering and appearance of the webpage content [120]. It is used to apply a style to the content created by the HTML. The CSS 3.0 version of CSS is used in this study.

JavaScript (JS): JavaScript files are used to control the behavior of webpages. The JS files are executed inside the web browsers on the client-side. The front-end development is mostly used in this study to develop a web-based PPGIS application.

jQuery: It is a light-weight and fast JavaScript library that is used for event handling and manipulation of HTML & CSS files [111]. The jQuery library is designed to make the use of JS easier in web development with "write less, do more" in mind.

Bootstrap: It is a free front-end web development framework used to develop fast, easier, and responsive web applications by using JS and CSS [112]. The advantage of using bootstrap is that developer has to focus only on the logical model and layout of the web application instead of web browser quirks. The BS4 is the latest version of bootstrap.

Leaflet JS Library: The Leaflet JS library provides better performance with its usability and simplicity as compared to other web mapping libraries. It will be used to display a map at the client-side without any additional requirements. It also supports the integration of plugins during web application development. The leaflet 1.7.1 version is used in this study.

Turf.js Library: Turf.js is an open-source JS library used to perform geospatial analysis on GeoJSON data [114]. It consists of many useful spatial analysis functions such as buffer, clip, and union, etc. In this study, the turf.js library is mainly used to perform buffer, within, clip, and measurement functions on the data. The turf.js library is simple to understand and use and it is also fast in processing time because it does not require sending the GeoJSON data to the server for processing.

ArcGIS JavaScript Library: It is an open-source and light-weight JS library to embed spatial tools in web applications [115]. The ArcGIS JS library provides many services to the developers and spatial analysis service is one of them. The spatial analysis service includes several functions that allow performing the spatial analyses on the data [116]. For this study, the "Service Area Analysis" function is used from the spatial analysis service.

5.2.2 Functional Requirements

The four functional requirements are integrated into the web-based PPGIS application during the development process: 1) Visualize map & data layers; 2) Spatial Analysis; 3) Contribute to improve the bikeability

Visualize Map & Data Layers: The leaflet JS library is used to add a base map to the application interface and provides the following controls to the users shown in figure-34;

1. **Zoom Control:** user can change the zoom level of the map by using the zoom control "+" and "-" buttons placed on the top left corner of the map.
2. **Default Extent Control:** user can go back to the default extent of the map by clicking on the "Home" button icon that appears on the top-left corner.

3. **Map Type Control:** Allow the user to select a map type ("Satellite", "Street" or "Gray Scale") from the layer control that appears on the top right corner of the map.
4. **Layer Control:** allows the user to add or remove a particular data layer on the map by using layer control. The layer control is provided on the top right corner of the map.
5. **Map Scale Control:** shows the current scale on the map in the metric system (miles).
6. **Map Controls:** user can freely move the map by mouse movement.

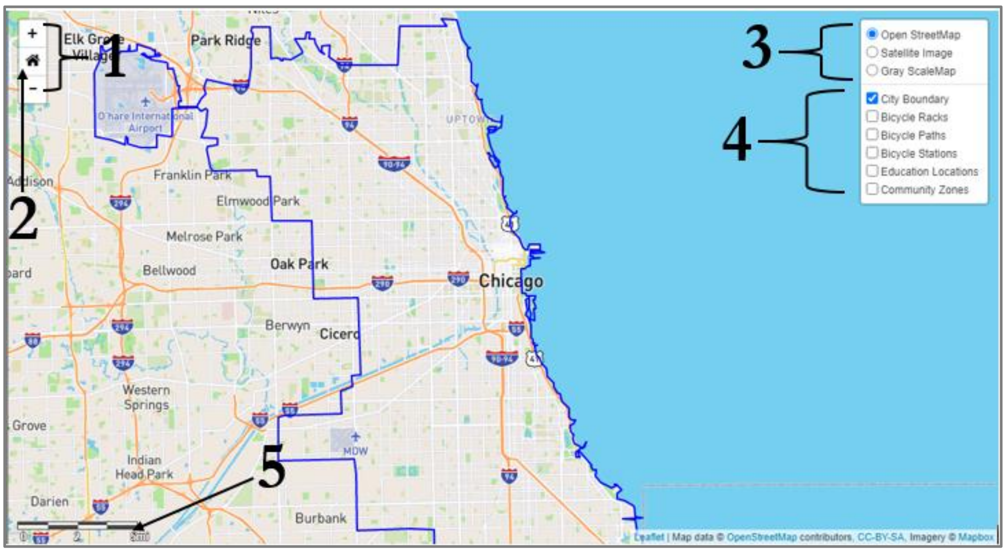


Figure 33: Map Interface of Web-based PPGIS Application

The leaflet JS library also supports the display of the GeoJSON data files, which is a format widely used to display spatial data on the map. The GeoJSON data format has many advantages over other spatial data formats such as Keyhole Markup Language (KML) and shapefile. Several web mapping API's support the GeoJSON format to display the data over the map. All the spatial data used in this study is converted to GeoJSON data format. There are several online tools available that convert the shapefile format to GeoJSON format. The online mapshaper.org platform is used to create the GeoJSON data [117]. The figure-35 shows the interface of mapshaper.org.

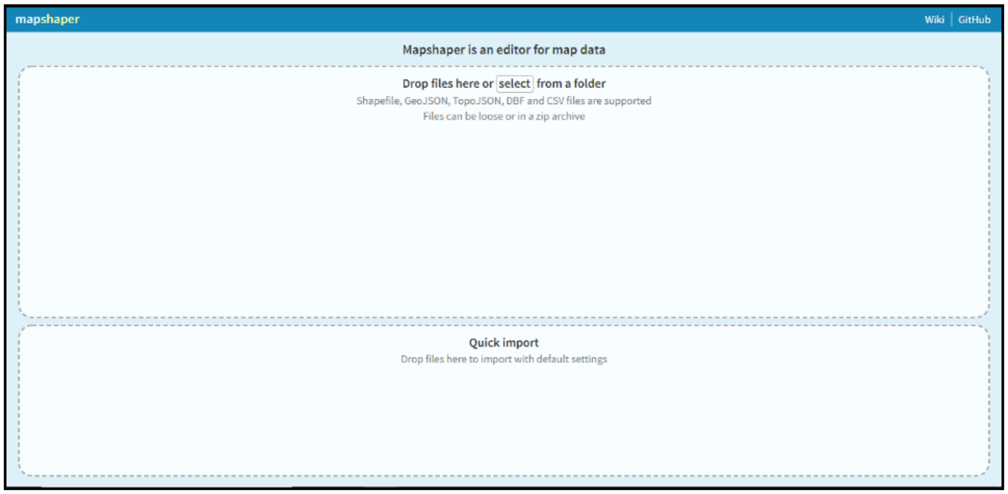


Figure 34: Interface of Mapsharper.org [117]

5.2.2.1 Integrating Spatial Analysis Tools

The integrating of different spatial analysis tools allows users to perform spatial analysis on the data. For this study, three spatial tools are selected and integrated into the web application: 1) Service Area Analysis 2) Bikeability Index 3) Heatmap

Service Area Analysis (SAA): Service Area Analysis calculates the distance that can be traveled by a road network from a particular feature (place) depending upon the specified time or distance value [118]. This analysis helps the user to visualize how much area can be accessed from a given location. The ArcGIS JavaScript API is used to perform the SAA on the bicycle parking facilities. If the user suggests a new bicycle parking facility, then he can also compute the service area from that location to identify how much area will be served from this new bicycle parking. The figure-36 shows the computed service area of existing bicycle parking facilities in yellow color on the map. On the left side, it also displays the total area that is accessible from existing bicycle parking facilities within 1 minute.

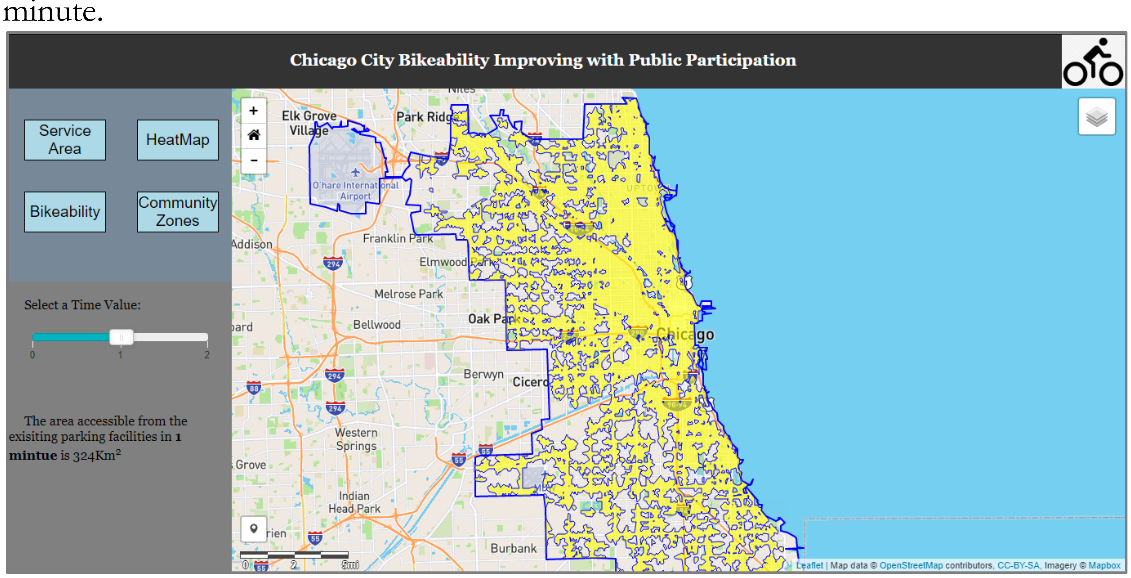


Figure 35: 1-Minute Service Area of Existing Bicycle Parking Facilities

Heatmap: Heatmap is a visualization tool that helps to identify where the higher density of spatial features occurs in the area. It helps to identify the significant patterns of the spatial data. The light-weight and open-source heatmap.js library developed by Patrick Wied is used to perform the heatmap analysis on the spatial data [119]. Once the user selects the data layer, the heatmap will be generated and displayed on the map. The color gradient scheme is used to visualize the heatmap results so that the higher density areas can be easily identified. The figure-37 shows the generated heatmap of bicycle stations data layer. The red color shows the higher densities of bicycle stations.

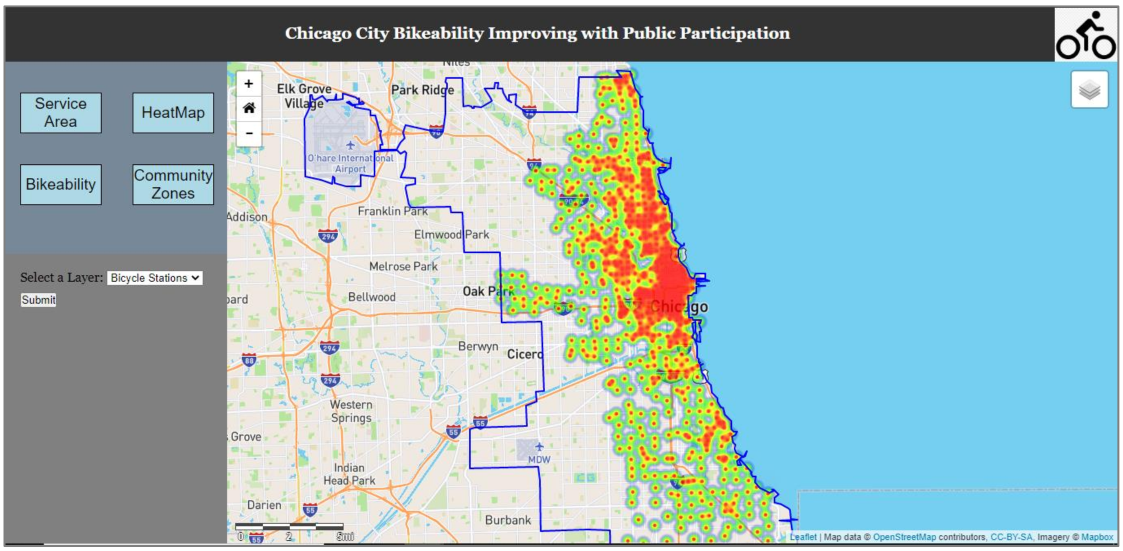


Figure 36: Heatmap of Bicycle Stations

Bikeability Index: A bikeability index is a useful approach of spatial analysis that includes different built-in environment factors to identify the bikeability condition in areas. The result of the bikeability index is represented in map form and identifying the areas that are less and more favorable for bicycling. The bikeability index is based on the Residential Density, Bicycle Infrastructure, Bicycle Parking Facilities, Topography, and Bicycle Safety factors. The figure-38 shows the bikeability index map on the map. On the left side, there is a pie chart that tells the percentage of the area of bikeability index classes.

Contribute to improving the bikeability: It allows the user to enter their suggestions on the map, such as placing a new bicycle parking facility, new bicycle route, or report about bicycle infrastructure such as street lights are not working, insufficient space in the existing bicycle parking facilities, etc. The user can also rerun the spatial analysis after placing the new bicycle parking to identify how much area will be served by this new facility. The figure-39 shows the result when the participant suggests a new bicycle parking facility and compute the service area of that location

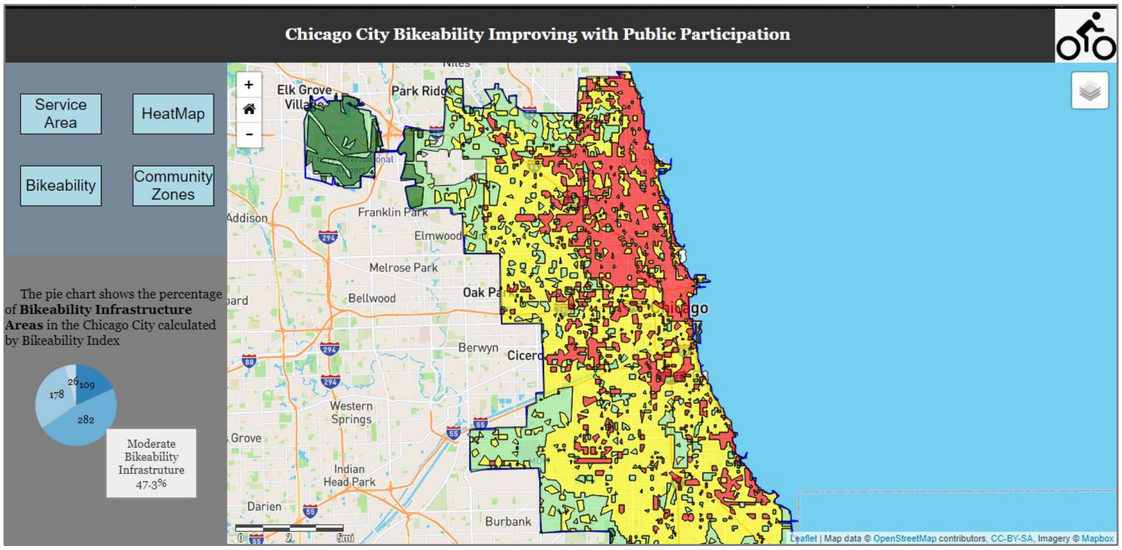


Figure 37: Bikeability Index Map Interface

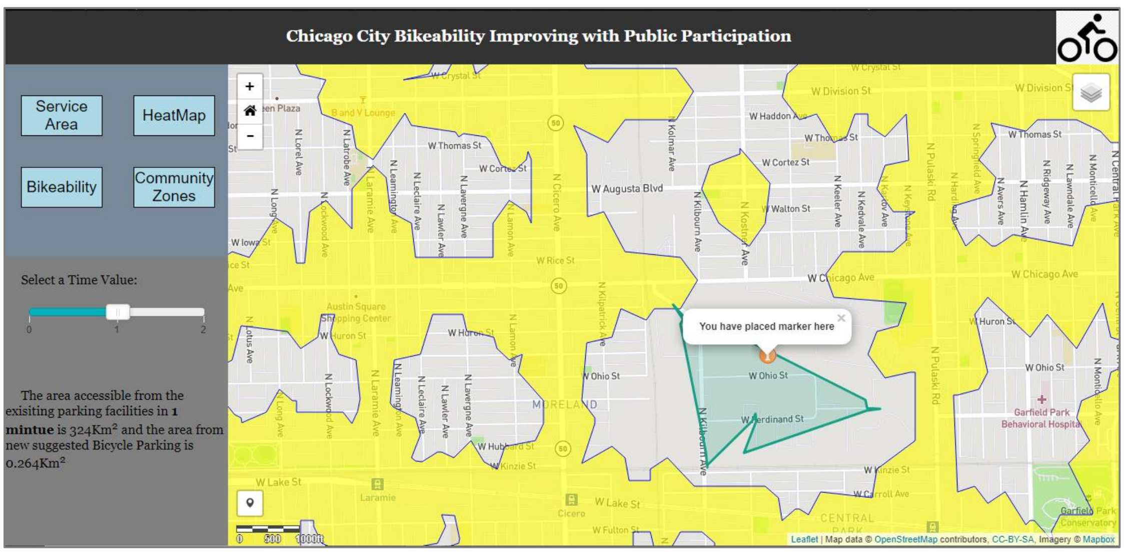


Figure 38: Suggesting a new Bicycle Parking Facility

6 Evaluation

This chapter explains the evaluation process for the usability and usefulness of application tools. The application evaluation is important to understand the experience of the user, identify the areas of application that need improvement, and effectiveness of the application. The quantitative approach is used to evaluate the application's usability and usefulness. The primary objective of the web-based PPGIS application is to evaluate whether the application helps to increase public participation during spatial planning and how they can easily use it.

After completing the implementation of the web application, the user study experiment with the help of participants is used for the user-centric evaluation with an objective for usability and usefulness aspects of the web application. The following section explains the selected evaluation criteria and methodology used for conducting user study experiment and their results.

6.1 Evaluation Criteria

In past, several web-based PPGIS applications focus on the technological parts and do not evaluate that tools are useful or not [19,68, 132]. The following criteria are selected to evaluate the designed web-based PPGIS application to examine does the application meets its objective or not.

Usability Evaluation:

The usability evaluation helps to understand how a particular application can be developed for the user's requirement so they can perform their task efficiently [133]. The usability evaluation process helps to collect the data about how the end-user uses the application to perform a particular task. The main objective of the usability evaluation is to determine the satisfaction level of the user for the application [134].

There are various standard evaluation tools that are used to evaluate the usability of the application. The System Usability Scale (SUS) developed by John Brooke in 1986 is one of the most popular and reliable standard tools used to evaluate the usability of the application with a small number of participants [135]. According to ISO 9241-11, the usability assessment determines the following characteristics of the application [136];

- Effectiveness: does the user able to complete their goals?
- Satisfaction: what is the satisfaction level of the user?
- Efficiency: Do the functionalities in the application help the user to achieve their goals?

The system usability scale contains 10 statements regarding various aspects of the application in which participants indicate their satisfaction and unsatisfaction level for the application. The 10 statements are divided into 2 portions, the half statements (evennumbered) are written in negative and the remaining half statements (odd-numbered) are written in positive for the application respectively. The five-point scale is used for each statement to get feedback from the user. The five-point scale has options from "Strongly Disagree" (1) to "Strongly Agree" (5).

The output of the system usability scale is a single value that represents the combined measure of application usability. The score value lies between the range of 0 to 100 and provides you the insight into the application usability.

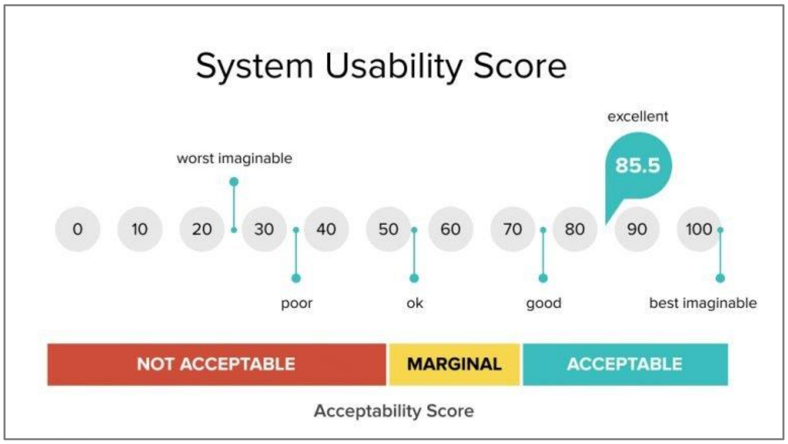


Figure 39: SUS Acceptability Score [137]

According to the system usability score scale, a score value of less than 50 is not acceptable and requires action to resolve the issues that stop the user to complete their particular task. The score value between 50 and 70 points to the problems of the application that need to be resolved. A score value greater than 70 is acceptable but needs minor improvements in the application.

Usefulness Evaluation:

The SUS only represents the overall usability of the application that is determined by the user's level of satisfaction. The system usability scale does not concentrate on the particular part or functionalities of the application. Moreover, it is difficult to identify the issues and part of the application which requires improvement to increase the usability of the application. Therefore a usefulness evaluation will be used to evaluate and identify the specific part or function and tools of the application which needs improvements. The figure-41 shows the overview of selected evaluation criteria.

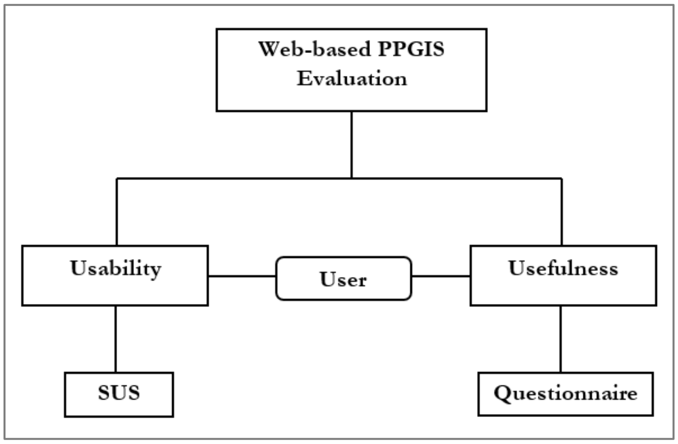


Figure 40: Application Evaluation Overview

6.2 User Study Experiment Methodology

The potential public participants were invited to participate in the user study experiment. The zoom (online-meeting platform) was being used between the participants and author for a user-study experiment. The author started the user study experiment with an introductory presentation of about 5 minutes in which participants were introduced to the application interface, tools, and describing the designed tasks that how to use the application to solve the assigned task. After that, participants were given 5-10 minutes to get familiar with the application. After that, the participant started to perform the five assigned task from which two are following;

- Task-1: Determine the areas which cannot be accessible within 1 minute of existing bicycle parking facilities by using the service area tool.
- Task-2: Suggest a new bicycle parking facility in the unserved area and find out how much area can be served from this location.

During the experiment, the author monitored the progress of participants while they were performing the task and they were only allowed to interact with the author in case of understanding the task and showed the result after performing the task. The author determined whether a participant was able to complete the task correctly or not.

For the usability evaluation of a web-based application, the system usability scale questionnaire was filled by the public participant after performing all the assigned tasks and the system usability score will be calculated from it. Similarly, the questionnaire was prepared to find out the usefulness of tools and particular part of the web application.

6.3 Evaluation Result

In the user study, 8 participants took part in the experiment, 5 male and 3 female from which all have at least bachelor's degree, 37% participants do not know about GIS knowledge and similarly 25% participants do not know about any web-mapping platforms (figure-42).

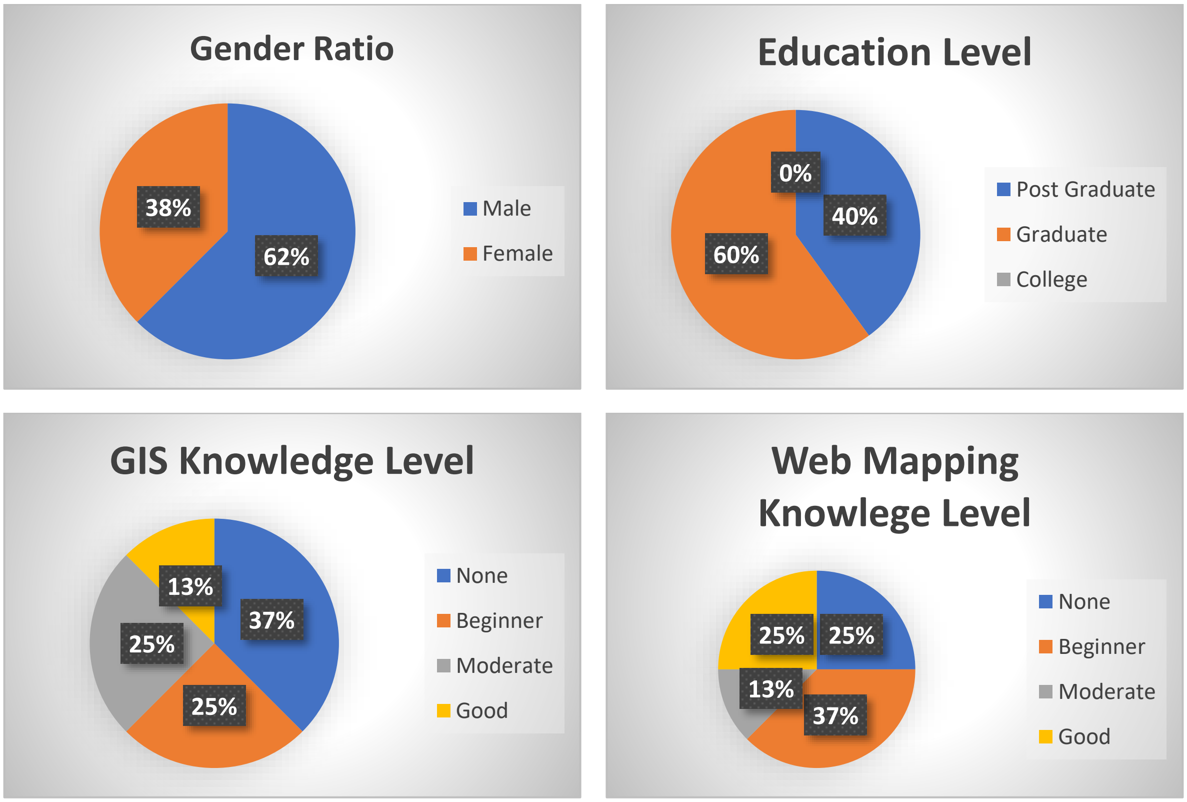


Figure 41: Participants Demographic Data

The application effectiveness was evaluated by completing the assigned task to the participants during the user study experiment. The table-6 shows the summary of the assigned task correctness. The task-1 and task-2 appear to be difficult compared to other tasks. The reason that why participants could not complete the task due to a lack of GIS knowledge and web-mapping. Overall participants were able to complete the most assigned task correctly

	Task-1	Task-2	Task-3	Task-4	Task-5	Overall
Participant-1	Right	Right	Right	Right	Right	100%
Participant-2	Right	Wrong	Right	Right	Wrong	60%
Participant-3	Wrong	Right	Right	Right	Right	80%
Participant-4	Right	Right	Right	Right	Right	100%
Participant-5	Right	Right	Wrong	Right	Right	80%
Participant-6	Wrong	Wrong	Right	Right	Right	60%
Participant-7	Right	Right	Right	Right	Right	100%
Participant-8	Right	Right	Right	Right	Right	100%
Overall	75%	75%	87.5%	100%	87.5%	

Table 6: Application Effectiveness

The SUS questionnaire was used to evaluate the web-based PPGIS application and filled out by the participants after performing the assigned tasks. The average SUS score value for the application usability evaluation was 84.6 (figure-43). According to figure-39, the application is acceptable if the SUS score is greater than 70. In our case, the SUS score is 84.6 which was near to the excellent SUS score (85.5).

SUS Questionnaire Response											
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Average
P1	5	2	5	1	4	2	4	1	4	1	87.5
P2	4	1	5	2	5	1	5	2	5	2	90
P3	4	1	4	2	5	1	4	2	5	2	85
P4	5	2	4	1	4	1	5	1	4	2	87.5
P5	3	2	4	2	4	1	4	1	5	2	80
P6	4	2	4	1	5	2	4	1	4	3	80
P7	5	2	4	2	4	2	5	2	5	2	82.5
P8	3	1	5	1	5	2	4	1	4	2	85
Average											84.6

Figure 42: System Usability Scale (SUS) with Average Score

The evaluation of the application tool usefulness was measured directly from the participant's responses to the questionnaire. The following charts (figure 43-45) show the participant's responses to the questions.

Question 1 - Do you think this web-based application will be a good platform for public participation for improving the bikeability of the city? The 62% of participants were strongly agreed and 13% were not agree that this platform could not a good for public participation (figure-44).

Question 2 - Do you think other local governments should have web applications like this to support public participation? The 50% of participants were strongly agreed and 13% were not agree and 37% of participants responses were neutral (figure-44).

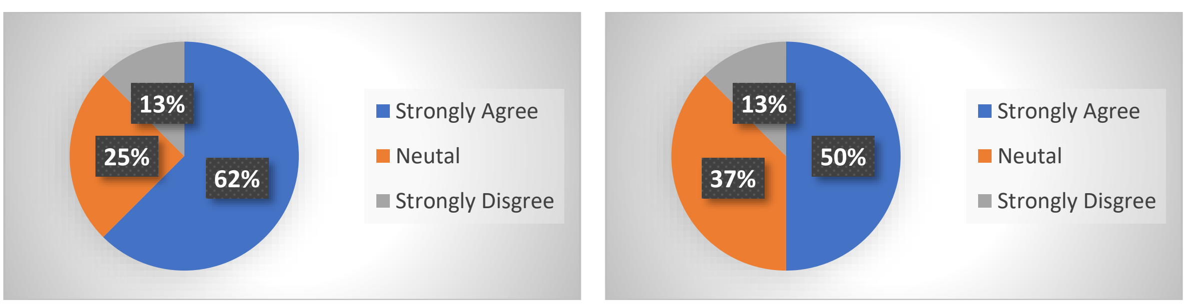
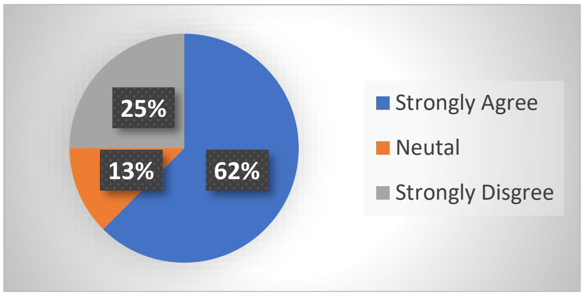


Figure 43: (Left) Participants Response to Q1 & (Right) Participants Response to Q2

Question 3 - Do you find the Heatmap tool relevant to perform analysis on the data? For this question, 62% of participants were strongly agreed and 25% were not agree that this tool is useful for the application usage (figure-45).

Question 4 - Do you find the Service Area Analysis tool useful for this application? The 75% of participants were strongly agreed that this tool is useful for the application (figure-45).



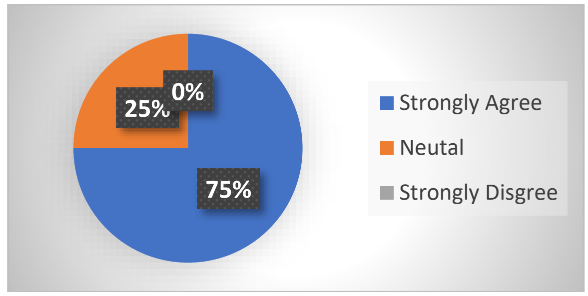


Figure 44: (Left) Participants Response to Q3 & (Right) Participants Response to Q4

Question 5 - Do you find the bikeability Index map helpful to visualize the bikeability conditions in the city? The 62% of participants were strongly agreed and 13% were not agree that this platform could not a good for public participation (figure-46).

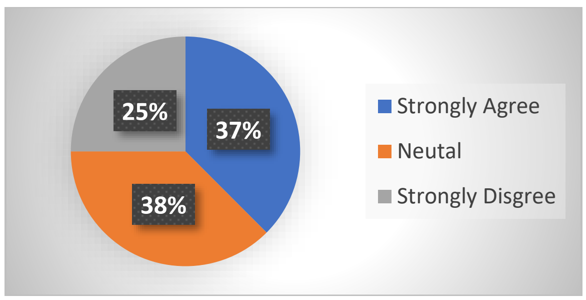


Figure 45: Participants Response to Q5

The questionnaire also contained two open questions related to further improvements in the application and what problems they faced during using the application. The table-7 shows the participant's responses (paraphrased) to the open question.

Open Questions	Responses
What difficulties do you face during using the application?	• cannot see the contributions made by other participants • cannot add more than 1 bicycle parking facility • Sometimes the service area analysis for new bicycle parking facility takes more time • does not give information that how many bicycles can be parked

	at a particular bicycle parking stand.
What do you think which parts of the application could be improved?	• One participant suggested there should be a facility to add pictures in the comment • There should be a facility on the application that their suggestion is accepted or rejected • Also, add street lights data of bicycle lanes on the map • Improve user interface

Table 7: Participant's responses to open question

6.4 Evaluation Summary

The usability and usefulness evaluation of the web application is important to know the efficiency of the application, to identify the improvements in the application, and help to understand the user's response. The usability evaluation of the web-based PPGIS application from the public participants has an 84.6 SUS score which indicates that the application is simple and easier to use, the functionalities and tools are integrated well and the end-user does not need any support to use this application although they do have any web-mapping and GIS knowledge. The results of the application tool's usefulness evaluation from the participants are found positive. The responses of participants indicate that this application is a good platform for public participation and the tools also help to perform the analysis on the current data and their contribution. The participant responses for the open questions also help to identify the deficiencies in the application and suggestions to improve the application.

7 Conclusion

The literature showed that existing public participation methods are not useful to involve and empower the public during spatial planning and decision-making processes due to poor communication between the public and concerned authorities. The main reason observed for limited public participation is time and place constraints for traditional public meetings. The existing participatory methods are not useful, particularly when spatial data is involved, and therefore it could be improved.

The public participation ladders are useful to define the roles or power given to the public in the spatial planning and decision-making processes. The rapid advancements in web and GIS technology help to improve and increase public participation. The time and place restriction can be solved with the integration of public participation, internet, and GIS to form web-based Public Participation GIS (WPPGIS) applications. The planning authorities can apply these technologies for collecting and processing the public opinions during spatial planning and decision-making process to provide better services and solve their problems.

This thesis study tries an attempt to design and implement the Web-based PPGGIS application with the integration of public participation, internet, and GIS components with the primary objective to increase the involvement and communication between planning authorities and the public during spatial planning and decision-making process.

First, the environment and built-in factors that contribute towards bikeability are identified from the existing literature to develop the bikeability index to measure bikeability. For developing the web-based PPGIS application, HTML, CSS, JavaScript, and frameworks of JS are used. For spatial analysis functionality, different libraries such as TurfJS, HeatMap library, and ArcGIS JS API are used. Similarly, the D3.js chart library is used to visualize the statistical data in the chart form. The web-based PPGIS allows the user to visualize different spatial data and contributes to improving the bikeability of the city. It also allows the user to run spatial analysis such as bikeability index, service area analysis, and heat map generation on the existing data and their contribution.

After implementing the web application, the user study experiment is conducted with 8 participants to evaluate the usability and tool usefulness of the application. The five design tasks are given to each participant to perform by using the application. Then System Usability Scale (SUS) method is used to evaluate the application's usability. The application has an 84.6 SUS score value near to excellent SUS score (85.5) value which indicates that the application is easy to use. The SUS only represents the overall usability of the application that is determined by the user's level of satisfaction. It does not evaluate the particular functionality of the application and difficult to identify the issues that need improvement. The questionnaire has been designed for the usefulness evaluation to evaluate the specific elements and functions of the application. The participant responses for the majority of the question are positive.

From the evaluation results, it shows that web-based PPGIS application provides easy and efficient ways to increase the communication between planning authorities and the public. The public can participate in the planning and decision-making process without any restriction of time and location. However, it is not always easy for all the public participants to use web-based PPGIS application if they do not have knowledge or experience of web-mapping and GIS.

7.1 Research Objectives and their Realization

Objective 1: Identify factors that contribute towards bikeability & develop a bikeability index.

Solution 1: From the literature review, five built-in and environmental indicators are identified that contribute towards the bikeability for this study. To generate the bikeability index and composite map, a Multicriteria and Weighted Overlay analysis are used. Because more than one factors have a direct influence on the public for bicycle usage. The bikeability index map helps the planners and public to examine the current bikeability condition in the area.

Objective 2 & 3: Design and develop a web-based PPGIS application to improve the bikeability of city with public participation.

Solution 2 & 3: The second and third objective of this study is fulfilled by designing and developing the web-based PPGIS that allows the public to improve the bikeability of the city by their contribution. The primary objective of this application is to increase public participation and increase the communication between planning authorities or the government and the public during the spatial planning and decision-making process. Open-source technologies such as JavaScript and its framework and spatial analysis libraries and API are used to implement the application. It allows the public to visualize the spatial data and make their contribution towards improving bikeability.

Objective 4: Evaluate the usability & usefulness of application

Solution 4: The fourth objective is to evaluate the usability and usefulness of the implemented application by using the user-study experiment. For this purpose 8 participants take part in the experiment and gets familiar with the concept of web-based PPGIS application by performing an assigned task to them. For application usability, the SUS is used and results in an 84.6 SUS score value which is near to the excellent SUS score value (85.5) and indicates that the application is easier is to use. Similarly, application usefulness is evaluated by the questionnaire about particular elements of the application, and the majority of questions get a positive response from participants.

7.2 Limitations

The limitation that are faced during this study are the following;

- Due to time limitations, the indicators that contribute towards bikeability are identified from the scientific literature review instead of getting public opinions about indicators from surveys.
- Due to the Covid-19 pandemic, the evaluation process is performed by using the online platform, and only a limited number of participants take part in the experiment. Similarly, the application is evaluated by any professional urban planner. The result of evaluation can be considered as preliminary only and require to be validated by a large number of participants in the experiment.
- Sometimes the service area analysis function took more time to get the result displayed on the map due to a large number of spatial features and affect the performance of the application.
- Due to time restrictions, we cannot work on the application reliability part. The administrators of web-based PPGIS applications must monitor the coming traffic on the application to track the IP address of the user. So only citizens of a city can participate in the spatial planning and decision-making process and ban other users from a different location.

To conclude this study, we observe the main advantage of the web-based PPGIS application overcome the time and place limitations of the traditional participatory methods. The web-based PPGIS are cost-effective ways to increase the communication between the public and concerned authorities during spatial planning and decision-making process. People can easily use and understand the application if they have little web-mapping experience.

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Appendix

System Usability Scale (SUS) Questionnaire

1. Do you think this web-based application is a good platform for public participation for improving the bikeability of the city?

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

2. Do you face difficulty while performing the task?

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

3. Do you find the analysis tools (heatmap, service area) relevant to the application?

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

4. Do you face difficulty in accessing the information about different data layers on the map?

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

5. Do you find the application innovative and easy to use?

	1	2	3	4	5	
Strongly Disagree	☐	☐	☐	☐	☐	Strongly Agree

6. Do you find any inconsistency in this application?

	1	2	3	4	5	
Strongly Disagree	▢	▢	▢	▢	▢	Strongly Agree

7. Do you feel confident while using the application?

	1	2	3	4	5	
Strongly Disagree	▢	▢	▢	▢	▢	Strongly Agree

8. Do you find the application unnecessarily complex?

	1	2	3	4	5	
Strongly Disagree	▢	▢	▢	▢	▢	Strongly Agree

9. Do you think that other participants can use this application easily?

	1	2	3	4	5	
Strongly Disagree	▢	▢	▢	▢	▢	Strongly Agree

10. Do you think you would need support to use this application?

	1	2	3	4	5	
Strongly Disagree	▢	▢	▢	▢	▢	Strongly Agree