



Evaluating the Impact of Urbanization on Environmental Sustainability through IoT-Based Tool

Master Thesis for a Degree in Computer Science: Innovation for Change in a Digital Society

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Computer Science: Innovation for Change in a Digital Society

Faculty of Technology and Society, Department of Computer Science and Media Technology, Malmö University Sweden

Two-year master's program

30 credits master's thesis: DA628E (TAICS)

Term: VT24

Supervisor: Dr Dipak Surie

Examiner: Helena Holmström Olsson

Popular Science Summary

An increasing proportion of people living in cities and their surroundings is called urbanization. Most people today reside in metropolitan areas for better jobs, medical services, schooling, and cultural opportunities. The United Nations estimates that nearly sixty percent of the global population will reside in metropolitan regions during the next three decades. In contrast, rapid and unexpected population growth frequently causes several problems, including air contamination, environmental degradation, sustainability challenges, and increased traffic. Therefore, growing urbanization is one-way global warming directly affects environmental sustainability. Many studies attest that integrating cutting-edge technology is essential to promoting sustainable urbanization and can improve the efficiency of urban systems such as IoT. The Internet of Things, or IoT, is an enormous structure of intelligent objects that can perceive conditions and communicate with one another to share data.

However, environmentally responsible growth is currently the top objective, guaranteeing that future generations enjoy an even better ecological system than ours. Therefore, the relationship between sustainable development and technology in urban areas requires further investigation. Ultimately, with the aid of developing technologies, responsible parties can create and implement workable methods to gauge the effect of urbanization on environmental sustainability.

This study examined how to use an IoT tool to assess how urbanization affects environmental sustainability. Forty-one primary publications were studied using a qualitative research methodology that included three crucial stages: a literature review, an experiment, and interviews. The study aimed to understand the challenges that urbanization poses to environmental sustainability and the role that emerging technology, particularly Internet of Things (IoT) systems, can play in assessing those impacts. Furthermore, this study proposed a design framework for urban planners and policymakers based on IoT, AI, and big data analytics to evaluate urbanization impacts. We also examined other research findings to understand further how to design and implement IoT systems in urban areas to create more sustainable societies. This study recommends improving sustainable urban centers by measuring environmental conditions with IoT technologies and the proposed framework.

Abstract

One of the most significant changes of the last two centuries has been urbanization, referred to as the relocation of residents from the countryside to towns and cities, with a rise in population equivalent to moving to cities. This massive shift to suburbia contributes to severe climate change challenges, creating enormous pressure on infrastructure, increasing energy consumption, CO₂ emissions, and using fossil fuels. Cities with buildings and transportation release more than 70% of the carbon footprint. By examining the 41 primary articles that comprised this research, we discovered that previous studies in this field have primarily focused on the theoretical and statistical foundation (see the reference list), with little attention paid to practical integration. In this case, practical integration entails designing and implementing the technology and running tests to observe preliminary outcomes of the application of developing technologies to promote sustainability in urban centers. Therefore, in this research, we aim to evaluate the impact of urbanization on different environmental metrics that compromise environmental sustainability. This research aims to develop an IoT-based tool to measure temperature, humidity, CO₂, eCO₂, and TVOC. This instrument can measure additional environmental parameters that prior research tools, such as eCO₂ and TVOC, could not measure. We are primarily developing this tool as a knowledge tool, utilizing interviews and preliminary data collection to identify vulnerable locations with potential for generalization.

Moreover, we proposed a design framework to tackle urbanization impacts in this study. We conducted this study using qualitative research methodology. We also conducted four experiments in the Malmö region and six semi-structured interviews with different individuals who are responsible for sustainability programs, environmental preservation, and urban planning. We evaluate the findings from interviews using thematic analysis. Ultimately, we relate the results from interviews and experiments to the research questions and discuss them critically. Finally, our results show no negative impact of urbanization on environmental sustainability in Malmö. The results of this research contribute to the existing body of literature and propose a framework that helps city planners, policymakers, and government officials get real-time data about environmental conditions to identify vulnerable locations and better planning for urban sustainability.

Keywords: Urbanization Impact, Environmental Sustainability, IOT, Digitalization, Air pollution

Acknowledgment

Let us begin by expressing our sincere gratitude to Allah the Almighty. Who gave us the willpower to finish our thesis by giving us a supportive family, top-notch instructors, and loyal friends. Second, we would like to thank our parents and whole family for their support throughout the journey. Nothing can adequately express their encouragement. We thank Dr. Dipak Surie, our supervisor, for his thoughtful guidance. To be supervised by him was our ideal job. His constant appreciation for his students is his most excellent quality. Despite his busy schedule, we appreciate his constant and prompt counsel, and he never failed to answer our questions.

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List of Acronyms

ICT	Information and Communication Technology
IoT	Internet of Things
AI	Artificial Intelligence
CC	Cloud Computing
GIS	Geographic Information System
RS	Remote Sensing
GI	Green Infrastructure
SDGs	Sustainable Development Goals
BRT	Bus Rapid Transit
RQ	Research Question
CO ₂	Carbon dioxide
eCO ₂	Equivalent Carbon dioxide
TVOC	Total Volatile Organic compounds

1 Introduction

One of the most significant changes of the last two centuries has been urbanization, referred to as the relocation of residents from the countryside to towns and cities, with a rise in population equivalent to moving to cities. Because of the speed at which urbanization occurs, cities are gradually replacing natural environments. More and more research has shown that growing cities causes a wide range of issues, including worldwide warming, loss of arable land owing to development, and contamination of water and the atmosphere (Fang et al., 2018).

The continuous urbanization and environmental degradation developments create logistical problems related to the impact of Urban Heat Island (UHI). Ward et al. (2016) mentioned that morphological transitions in land cover occur in cities due to urbanization, probably prompted by industrial development. According to Bibri & Krogstie (2020), urban growth places enormous pressure on infrastructure, increasing energy consumption and other resources. These issues imperil the ecological viability of communities. The energy sector, a central municipal domain, mainly produces global releases of greenhouse gases.

The long-term sustainability of ecosystems remains the most contentious of the many unresolved social and fiscal challenges from the past few years. The persistent adverse effects of global warming still threaten environmental sustainability (Wang et al., 2023). Globally, cities are essential to national and provincial economies and the social construction of their respective nations. Cities provide opportunities for occupations, schooling, amenities, and social stimulation; their share of national economies is excessive. There has been an ongoing plunge in the amount and caliber of open green spaces in metropolitan areas. Over the next thirty years, more than half of the global population will live in urban centers. This massive shift to suburbia is contributing to severe climate change challenges, such as increased CO₂ emissions and the use of fossil fuels (Korányi et al., 2021). As a result, Fiscal et al. (2021) reveal that based on the estimation of the UN Climate efforts, more than 70% of the carbon footprint is released by cities, with buildings and transportation being the two main contributors. So, we must promote urban sustainability everywhere.

It is essential to cut the volume of carbon emissions in the air (Turner-Skoff & Cavender, 2019). Agache et al. (2022) research suggests urbanization has increased temperature and environmental carbon emissions due to human activities. Due to this, more than a hundred thousand deaths were reported yearly in recent decades.

Goel and Vishnoi (2022) mentioned that advancement in digital technology allows us to track the environment and forecast the results of urbanization's impact on environmental sustainability with the help of contemporary technology. All this is possible with the evolution of technology in information and communication technology (ICT). Novel solutions are paramount if we want to develop a sustainable community. With the revolution of Industry 4.0, many sectors utilize digital solutions in their different operations. Contemporary technological networks, applications, and tools increasingly enhance the sustainability of urban life (Balogun et al., 2020). These developments can change the face of urban growth due to the rapid trend of urbanization, turning communities into long-term sustainability centers and a sense of environmental responsibility.

1.1 Significance and Motivation

The massive and unsupervised expansion of urban growth causes environmental issues. Urbanization presents problems to almost every government, including sustainability, accommodation, transportation, and energy consumption. Cities are places of innovation that provide opportunities for technological development and space to deal with environmental issues, and their share of national economies is excessive (Li et al., 2016). Hwang et al. (2017) mentioned that human energy use is the primary source of CO₂ in the atmosphere. Understanding the environmental consequences of urbanization is crucial to formulating efficient approaches for sustainable development. Different construction activities and urban designs can negatively affect the natural surroundings. Therefore, environmentally friendly urban growth is necessary to save communities and the environment. Therefore, emerging technologies are required to describe the effects of rapid urbanization on environmental sustainability (Bibri & Krogstie, 2020).

Bibri et al. (2024) research reveals numerous environmental issues in urban centers, such as air pollution, CO₂, and high temperatures. The emergence of technology, especially artificial intelligence, might be an excellent option to eliminate those issues. Echendu and Okafor (2021) suggest that using intelligent technologies in environmental monitoring and urban design allows cities to improve their lifestyle and enhance overall sustainability.

1.2 Purpose and Objectives

Our objective in this research is to investigate the impact of urbanization on environmental sustainability using emerging technologies.

The objectives are the following:

- To examine the function of digital tools in enhancing sustainability.
- To develop an IoT-based digital tool for evaluating urbanization's impact on environmental sustainability.
- To highlight the importance of digital tools and propose a design framework for integrating emerging technologies in urban environmental sustainability.

1.3 Problem Statement

Prior research verifies that the utilization of emerging technology is a crucial component in advancing sustainable urbanization, and it has the strength to foster the effectiveness of urban systems. Moreover, researchers must further investigate how technology and environmental sustainability interact in urban areas. After examining the 41 primary articles that comprised this research, we discovered that existing work focuses more on the theoretical and statistical foundation (see the reference list), with little attention paid to the practical integration of emerging technologies. Therefore, there is a need for more research to implement practical solutions with the help of emerging technology to measure the impact of urbanization on environmental sustainability. In this instance, putting the technology to use and conducting tests to see early results about applying emerging technologies to improve sustainability in urban areas constitute practical integration. So, it is essential to evaluate these complications from an academic point of view thoroughly. Therefore, this thesis aims to explore a problem space in terms of how things operate and to create a more practical technology solution to address the problem by practically integrating IoT technology in an urban context.

1.4 Relevance of the Problem

To ensure that subsequent generations relish an even better ecological system than ours, environmentally conscious growth is currently the main priority (Ali et al., 2019). Therefore, the utilization of emerging technologies, including Artificial Intelligence (AI), the Internet of Things (IoT), and Geographic Information Systems (GIS) has led to significant changes in some areas, such as urban growth, environmental responsibility, and global warming. According to Bibri et al. (2024), Utilizing these technologies significantly impacts resource management. This also helps urban developers and policymakers to develop more eco-friendly cities.

1.5 Research Questions

By considering the gap in existing research, this research aims to answer the following research questions:

1. How does urbanization affect various environmental metrics related to sustainability?
2. How to design and integrate IoT-based tools to evaluate urbanization impact on environmental sustainability?

The objective of the first research question is to explore and understand how urbanization affects different environmental indicators, such as carbon dioxide, air pollution, and greenhouse gases, that impact environmental sustainability. Moreover, the second research question explores the capability of technology, mainly IoT, and how we can practically implement this technology for real-time data monitoring to enhance the sustainability of the environment.

1.6 Thesis Structure

The researchers organized the research as follows: Section 2 covers the literature review, section 3 presents the research methodology that is used in this research to answer the research questions, section 4 covers results, section 5 covers analysis, section 6 covers the discussion, and the last section 7 summarizes the research and addresses its limitations.

2 Background

One significant worldwide shift is urbanization. By 2030, experts expect five billion people, roughly sixty percent of the worldwide population, will live in urban areas. As a result, numerous issues are brought on by this, such as dense populations in cities, heavy traffic, inadequate energy, unplanned growth, and a dearth of essential services (Bansal et al.,2015). The literature review contains a comprehensive analysis of academic publications focusing on how digital tools and technology function to reduce the negative impacts of urbanization on environmental sustainability.

2.1 Core Concepts: Urbanization, Digitalization, and Environmental Sustainability

The following section provides definitions of urbanization, digitalization, and environmental sustainability. To fully understand the relationships and implications examined in this research, one must have a solid understanding of these fundamental terms.

2.1.1 Urbanization

Bansal et al. (2015) describe urbanization as a growing percentage of people residing in cities and surrounding areas. Over 50% of the global population resides in urban areas, primarily densely populated cities. According to Chen et al. (2022), urbanization is the term used to describe how the productivity of people and occupations has changed from village to suburban areas. This includes modifications in the geography, number of residents, and other economic activities. Another definition by Gross and Ouyang (2021) suggests that urbanization is a multifaceted phenomenon encompassing more than just movement; it may also signify a rise in population or reorganization. Urbanization continuously concentrates an abundance of individuals in a highly tiny region to form a town. Different authors describe urbanization in many ways. Still, in the context of this thesis, we consider urbanization to be the transformation of a growing percentage of humans residing in cities.

2.1.2 Digitalization

The term "digitalization" lacks a precise definition. Gradillas and Thomas (2023) claim that the term "digitalization" is being utilized to describe procedures for gathering, producing, and analyzing data to add worth and foster creativity. Most people define *digitalization* as applying digital tools to create new chances for value creation (Ruggerio, 2021). According to Mura and Donath (2023), digitalization is multifaceted. Scientists and ethicists discuss it from varying viewpoints, depending on the circumstances. A commonly acknowledged concept links it to the modern economy, considered a novel strategy for companies founded on advancement. Researchers often link digitalization with digital transformation. As Feroz et al. (2021) mentioned, "digital transformation" describes the extraordinary changes in communities, economies, and companies. It applies new digital technology to facilitate significant operational changes, including improving client relationships or developing novel industries. According to Gobble (2018) of the Harvard Business Review, a study by James Manyika and colleagues showed that companies that had embraced digital advancements continued to maintain an extensive and enduring gap in productivity and performance.

Moreover, digitalization has changed the way of working across different sectors, such as IT functions. In addition to becoming more productive, business activities would only be present with information technology (Urbach et al., 2018). The advent of Industry 4.0 signifies a noteworthy transformation in the industrial sector through digitization. Another instance of this is the digital design of the Boeing 777 airplane (Zhou, 2013). These advancements have transformed towns into sustainability and environmental responsibility hubs, altering the face of urban progress.

2.1.3 Environmental Sustainability

Sustainability is hard to define because of its ethical element and comprehensive nature. It has multiple parts and is a somewhat sophisticated idea. It advances humanity while preserving the systems' robustness governing the economy, community, and environment (Sundsgaard, 2021). According to Ruggerio (2021), environmental sustainability refers to the administration of environmental policy and other fields to manage the use of resources and reduce the impact of climate change. The integration of the fourth industrial revolution and the sustainable economy has highlighted environmental sustainability, aiming to enhance the efficacy of resource utilization. It justifies maintaining the environment for the benefit of the future and not sacrificing environmental standards in meeting human demands (Feroz et al., 2021).

2.2 Evaluating Urbanization Impact Through Data-Driven Approach

This section describes the data-driven approach used in existing studies by many authors to evaluate urbanization impact. It involves applying numerous statistical techniques to selected data (open-source data).

A significant global urbanization trend has recently raised severe worries about environmental deterioration. Numerous empirical investigations have examined how urbanization affects ecosystems in many different nations. Ali et al. (2019) found a positive correlation between worldwide urbanization and carbon emissions using 23 years from 1975- 1998 data from 86 nations. Another author carried out a second study in the Middle East and North Africa, and their findings demonstrate the positive effect of urbanization on energy consumption and CO₂ emissions. Wang et al. (2016) investigated the impact of the BRICS countries' urban population on carbon emissions, among other things.

The third study valued the effects of gentrification, age distribution, and population growth on energy use and carbon dioxide emissions. The author found a significant correlation between urbanization's energy utilization and carbon release using the GMM technique. A Pakistani study conducted by Ali et al. (2019) provides valuable insights into the Auto Regressive Distributed Lag (ARDL) bound testing technique for short- and long-term evaluation using historical time series data from 1972 to 2014. Their conclusion implies that the variables had cointegration. Their findings also suggest that government actions are necessary to facilitate the adoption of environmentally friendly innovations in the urban industrial and residential sectors. Additionally, they propose initiating public awareness and education projects to address ecological damage, prevention, and modification.

Moreover, Ali et al. (2019) stated that another research evaluates the impact of population growth on utility usage and the release of carbon dioxide. They separated the ninety-nine countries into three income categories using balanced yearly panel data

covering 1975–2005, including low, middle, and high. This study found that while sprawl positively affects the ecosystem across all income levels, it is most noticeable in the middle class.

2.3 Urbanization and Environmental Sustainability

As Agboola and Tunay (2023) defined *urbanization* as individuals migrating from the countryside to urban centers, this trend continues globally today. Therefore, integrating information and communication technology (ICT) is essential for determining how cities are developed. Conversely, Brom et al.'s research from 2023 emphasizes how crucial it is to have a GIS-based decision support tool that incorporates climate resilience goals into urban planning while developing green infrastructure during increased urbanization.

According to Ali et al. (2019), environmentally conscious growth is the main priority to ensure that subsequent generations relish an even better ecological system than ours. Different studies show how natural surroundings were affected by urbanization. A study by Karlilar et al. (2023) suggests that digitalization has become an essential factor in reducing pollution, and it can facilitate a low-carbon economy. Moreover, their study also evaluates the effect of digitalization and green policies on achieving environmental sustainability. Balsalobre-Lorente et al. (2023) mentioned that in this contemporary era, the world faces many problems, the most crucial being environmental sustainability. Therefore, emerging technologies such as artificial intelligence can play a vital role in overcoming those problems.

Urban planning and environmental sustainability are often interlinked. Progressive development is important as urban growth creates many challenges, such as resource utilization and carbon emissions in cities (Chen et al., 2023). Additionally, Danish et al. (2023) mentioned that the mining of fossil fuels emits many chemicals and waste components, which causes air and water pollution.

2.4 Developments in Urban Management

2.4.1 Smart Sustainable Cities

The term "smart city" is characterized as a creative urban area that leverages the power of information and communication technologies (ICTs) to boost productivity, the standard of living, and metropolitan management and convenience while making sure that it fulfills the demands of generation after generation in terms of the cultural, environmental, and social variables (Echendu & Okafor, 2021). Worldwide developments like the growth of ICT, urbanization, and sustainability have shaped the idea of intelligent and sustainable cities (Bibri & Krogstie, 2017a). The notion of thoughtful, intelligent cities emerged in 2010 as an innovative trend in urban technology. It focuses on utilizing distributed computing and ICT to accelerate the shift to sustainable growth, which is necessary in an expanding urban society. As a result, research organizations, academic institutions, lawmakers, officials, and ICT firms are paying increasing importance to creating environmentally conscious cities as a potential solution to the impending sustainability and urbanization concerns (Bibri, 2018).

It is possible to discuss cities becoming smarter in dealing with sustainability and social issues as well as offering assistance for citizens to enhance the standards of their lives as ICT defines structures, engineering, and urban concepts. The introduction of ICT into urban environments suggests the existence of new and more extensive collections of urban statistics, which can offer a plethora of opportunities for better monitoring,

comprehending, analyzing, and planning intelligent, sustainable cities to enhance their value to the objectives of sustainable development (Bibri & Krogstie, 2017b). Integrating urban ICT in many forms, like the Internet of Things, will help better harness and stimulate application for the wide range of urban sustainability. Thus, it is possible to promote sustainable urban development by utilizing the capabilities of modern IoT for tracking, evaluating, and designing cities (Alavi et al., 2018).

2.4.2 Eco-friendly Infrastructure and Urban Design

Turner-Skoff and Cavender (2019) underscore the pivotal role of trees amid climate change and their involvement in achieving the UN's sustainable development goals. It is beneficial to have open green spaces in cities because they play a positive role in minimizing the effects of climate change. The initiative to plant more trees in cities is progressing to make urban areas more sustainable in the face of climate change (Salmond et al., 2016). Using GIS and remote sensing techniques helps city planners provide spatial data about specific land for green spaces (Brom et al., 2023).

Urban green infrastructure can help modify cities according to climate change. Moreover, it can be helpful and essential in making more sustainable cities (Sturiale & Scuderi, 2019). Urban planners can utilize real-time data from remote sensing techniques and analytical methods to select multiple city greenery locations (Bibri et al., 2024). Trees have the potential to mitigate contaminants in the air, capture rainwater, and enhance the purity of runoff water. Additionally, green infrastructure promotes sustainability while preserving terrestrial and aquatic life (Turner-Skoff & Cavender, 2019). Urban flourishing greenery constitutes an essential for enhancing sustainability because it fosters the growth of habitats supporting a wide range of species, reduces emissions, provides shadows to mitigate the city's heatwave effect, and controls temperature through vaporization (Alshuwaikhat et al., 2022).

2.4.3 Resilient Energy and Mobility Infrastructure

The world's sustainability requires extra caution when expanding the transit network. Therefore, innovation can support environmentally friendly mobility by enhancing recycling, lowering emissions, providing communication-based travel alternatives, and helping accomplish the (SDG) goals (Shah et al., 2021). Evidence suggests that when considering strategies to reduce carbon dioxide emissions, supporting renewable energies is particularly successful among them (Wang et al., 2023). For instance, Bus Rapid Transit (BRT) and renewable energy sources are viable, ecological alternatives to automobiles for lowering carbon dioxide emissions in several locations (Mostachjov, 2015). With the advent of communal transportation, the sharing economy emphasizes the technology-driven reduction of carbon emissions and traffic jams by allowing users to share vehicles rather than owning them, which advances environmentally sustainable transportation and improves sustainability in general (Santos, 2018). Developing technologies, such as smart power plants, advanced traffic lights, smart buildings, innovative recycling, smart vehicles, and smart ecological monitoring, are practical methods for reducing greenhouse gases. Emerging technology and efficient solutions make urban systems more sustainable and open opportunities for innovative solutions (Bibri et al., 2024).

2.5 Digital Resources for Assessing the Effects of Urbanization

As Balogun et al. (2020) mentioned, using technology is vital to developing sustainable cities in an era of urbanization. Different emerging techniques, i.e., ICT, AI, GIS remote sensing, and IoT, are significant in observing the effects of urbanization on environmental sustainability.

As mentioned by Kopetz and Steiner (2022), the Internet of Things is a network in which many devices are connected to share data with the help of the Internet. Data collection and analysis methods have changed the city monitoring system with the help of IoT. The Internet of Things (IoT) is an exciting concept developing into an increasingly complex network of gadgets and sensing devices. It will likely encompass many commonplace items, such as humans, structures, water sources, and monitoring environmental factors. The Internet of Things aims to accomplish many brilliant activities through interaction and data sharing, such as linking with objects and observing and tracking objects (Bibri, 2018). According to Bibri et al (2024), IoT provides environmental information such as air quality, water quality, noise levels, and temperature. Sensors can be placed in all the critical positions of cities for real-time tracking and data transmission. The information finds high-risk areas that need to be monitored and serves as an instrument for environmental changes. Additionally, big data and analytics innovation enable businesses to handle and comprehend massive amounts of sensor data. These Technological tools within the urbanization trend offer copious, organized, broad, well-defined, and reasonably priced data regarding urban processes and activities, enabling continuous analysis and flexible strategic and tactical approaches (Bibri & Krogstie, 2020).

Authors	Description	Publication Type	Limitations
Echendu and Okafor (2021)	This study examines the existing literature on smart city technologies by utilizing Singapore as a basis to tackle the adaptability of technology and how technology addresses African urbanization challenges.	Journal	<ul style="list-style-type: none"> Does not describe the practical integration of smart technologies. Absence of source information and document screening standards. More emphasis needs to be placed on using IoT.
Wang et al. (2023)	This study explores the importance of green policies in BRICS countries to reduce CO2 emissions and	Journal	<ul style="list-style-type: none"> Does not describe the practical integration of

	other pollution to ensure sustainability.		<p>smart technologies.</p> <ul style="list-style-type: none"> • Absence of source information and document screening standards. • There is no emphasis on using IoT.
Bansal et al. (2015)	This study explores the challenges of urbanization and how including unique strategies leads to achieving sustainability.	Reviewed Paper	<ul style="list-style-type: none"> • Does not describe the practical integration of smart technologies. • Absence of source information and document screening standards. • There is no emphasis on using IoT.
Bibri (2018)	This article examines the relevant literature on the purpose of big data apps powered by IoT sensors to make a sustainable environment under the framework of smart cities.	Journal	<ul style="list-style-type: none"> • Does not describe the practical integration of smart technologies. • There is less focus on urbanization challenges.
Goel and Vishnoi (2022)	This study investigates the challenges of urbanization in developing countries and how ICT can enhance sustainable urbanization	Journal	<ul style="list-style-type: none"> • Does not describe the practical integration of smart technologies. • Absence of source information and document screening standards.

			<ul style="list-style-type: none"> • Less emphasis on IoT
Bibri and Krogstie (2020)	This paper investigates the significance of intelligent strategies and emerging technologies in creating a more sustainable environment under the concept of smart cities in Stockholm and Barcelona.	Journal	<ul style="list-style-type: none"> • Does not describe the practical integration of smart technologies.
Bibri et al. (2024)	This study investigates the function of eco-cities and the artificial intelligence of things to promote environmental sustainability.	Journal	<ul style="list-style-type: none"> • Does not describe the practical integration of smart technologies.
Balsalobre-Lorente et al. (2023)	This study used statistical methods to investigate the CO2 emissions due to urbanization and tourism and the importance of ICT in reducing those impacts in 36 OECD nations.	Journal	<ul style="list-style-type: none"> • Does not describe the practical integration of smart technologies. • Absence of source information and document screening standards. • Less emphasis on IoT.
Hui et al. (2023)	This study explores the importance of green spaces and intelligent technologies in monitoring the environment and enhancing city sustainability.	Journal	<ul style="list-style-type: none"> • Does not describe the practical integration of smart technologies.

Balogun et al. (2020)	This study examines nine different cases to investigate the potential of digitalization in addressing climate-related problems.	Journal	<ul style="list-style-type: none"> • Does not describe the practical integration of smart technologies. • Absence of source information and document screening standards. • There is little emphasis on using IoT.
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Table 1: Relevant Studies in Literature

Echendu and Okafor (2021) performed a literature review on innovative city technologies, and their results show that employing these digital and innovative technologies can help identify the problem of urbanization in the context of Africa and enhance the safety of their residents. The statistical technique STIPRAT is utilized by Wang et al. (2023) on the BRICS nations from 1995 to 2019. His findings show that including green spaces and digitalization eliminates the amount of carbon emission in the atmosphere. Bansal et al. (2015) describe the trend and the challenges associated with urbanization in literature. His finding suggests that smart urbanization is vital in protecting the future of towns. Bibri (2018) reviewed the existing literature to identify the objectives of big data apps that enable IoT for environmental sustainability under the smart city's framework. His findings aid lawmakers and city planners in utilizing technology for environmental advantages. Goel and Vishnoi (2022) highlight the issues developing nations face and the emergence of ICTS technology, especially in low-income countries, to foster sustainable urbanization.

Thus, in this work, we attempt to construct an IoT toolkit to measure environmental indicators. Our toolkit measures new environmental variables, such as eCO₂ and TVOC, in addition to conventional metrics, such as CO₂, temperature, and humidity. Measuring these additional parameters makes it possible to better understand the environmental conditions. Throughout the process, we save sensory data in CSV format using the Arduino IDE and Jupyter Notebook and utilize Python libraries to visualize it.

2.6 Research Gap

Many existing studies mentioned in Table 1 describe the significance of Information and Communication Technology (ICT), Artificial Intelligence (AI), the Internet of Things (IoT), and Big Data Analytics. However, they need to focus on how these new technologies and digital tools may address environmental sustainability challenges in an urban setting, which closes a significant gap in the literature and practice today. Therefore, in this research, we reviewed the existing literature to understand the current problems of rapid urbanization and how it affects environmental sustainability. Additionally, we developed a helpful application based on the Internet of Things (IoT) to track and measure various

environmental elements impacted by urbanization through different practical experiments. This tool provides up-to-date environmental information for improved urban planning.

Furthermore, this study proposed a valuable design framework for policymakers, urban planners, and other municipal stakeholders to minimize the effects of urbanization and enhance environmental sustainability with the help of IoT, AI, and Big Data Analytics. This study is a step toward using different emerging technologies to promote sustainability in urban centers. The knowledge gained from this study can be applied in different contexts to promote best practices for sustainable urban development.

3 Methodology

This study aims to assess how urbanization affects environmental sustainability and attempts to address the research questions listed in Table 2.

Research Questions	Objectives
RQ1: How does urbanization affect various environmental metrics related to sustainability?	The objective of this research question is to identify the environmental metrics that are most affected by urbanization.
RQ2: How to design and integrate IoT-based tools to evaluate urbanization impact on environmental sustainability?	Investigate the importance of emerging technology and how to design and implement IoT tools in urban contexts to evaluate urbanization impact.

Table 2: Research Questions with Objectives

3.1 Research Methods

This study includes the qualitative research methodology in which the data was collected by conducting participant interviews. The participants' viewpoints were analyzed according to different factors, such as the effect of urbanization, environmental sustainability, and integrating emerging technologies, which play essential roles in developing sustainable societies (Oates et al., 2022). The existing theories in the literature can also help collect qualitative data (Denscombe, 2018). This study collected data using three basic methods: literature review, experimentation, and semi-structured interviews, as depicted in Figure 1.

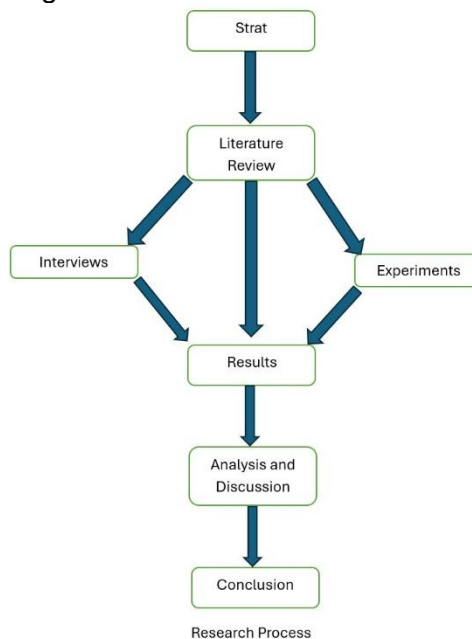


Figure 1: Research Process

3.1.1 Literature Review

Kitchenham first presented a strategy for systematically conducting literature reviews, which many others adopted. To conduct literature reviews for this study, the Kitchenham technique will be used, which Prabowo et al. (2021) also implemented in their study.

We answered the first research question with the help of a literature review. We conducted an in-depth literature analysis to gather information from earlier research and theories, providing a qualitative basis for understanding the effect of urbanization on the environment and contextual nuances. Denscombe (2018) noted that conducting a literature review involves using existing academic, commercial, and real-time data to obtain meaningful insights into several fields related to this study. The related fields include sustainable development and environmental sustainability, urbanization impact and trends, and integrating emerging technologies and IoT. A critical examination of the literature served as the theoretical cornerstone for this investigation. After studying several concepts and theories, an IoT-based tool is suggested based on the author's knowledge. Consequently, the literature review served as a guide to direct our study toward our goals.

3.1.1.1 Procedure for Study Selection

To finish the decision-making process of the fundamental research depicted in Figure 2, we performed the following actions:

1. Using the keywords, creating a search string, and applying it to pertinent data sources.
2. 478 documents have been retrieved using the search string across all data sources.
3. Thirteen duplicate papers from the chosen data sources were eliminated.
4. 382 publications were removed according to keywords, titles, and abstracts incompatible with the study's parameters.
5. Forty-seven papers were filtered using inclusion and exclusion criteria.
6. A bibliography of 36 papers was reviewed using the reverse snowball to find five additional publications.

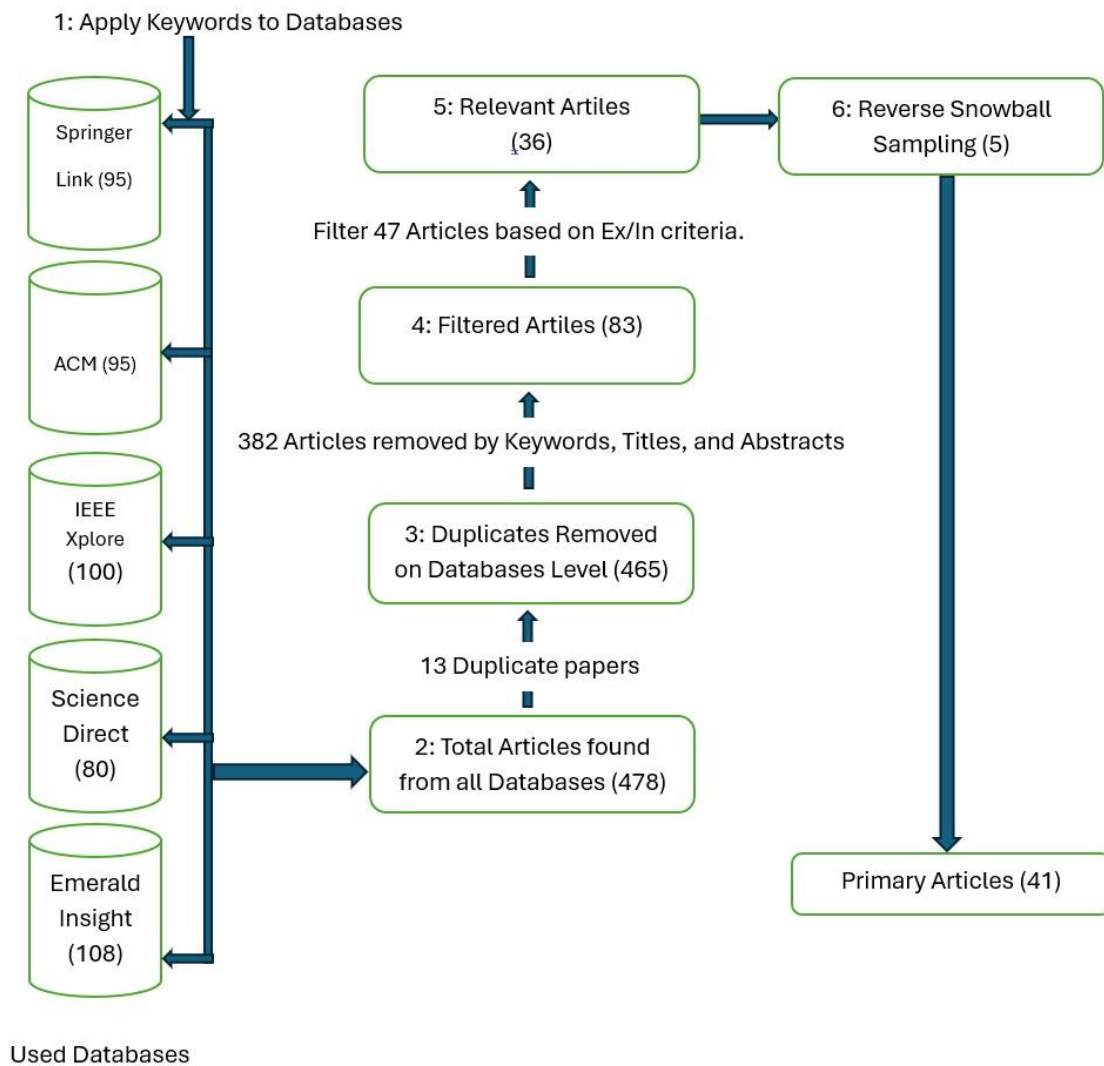


Figure 2: Literature Search Process

3.1.1.2 Search String Formulation

The following section details the search terms and sources we utilized to retrieve publications about the study's focus. We employed various keywords from the research questions to locate pertinent material for this study. The keywords were divided into three categories, A, B, and C because the research questions focus on tying together three aspects: urbanization impact, environmental sustainability, and integration of digital technologies.

Group A: General terms associated with this research are found in Group A (urbanization, urbanization trends, global urbanization impact, etc).

Group B: Group B concentrated on (air pollution, sustainability, green infrastructure, environmental sustainability, etc).

Group C: Search terms about (digitalization, IoT, smart, sustainable cities, etc.) can be found in Group C.

The following search query was entered into scientific databases to locate related papers.

(urbanization OR urbanization trends OR urbanization impact) and (air pollution OR sustainability OR green infrastructure OR environmental sustainability OR sustainable development) and (digitalization OR smart cities OR sustainable cities OR IoT).

We extracted the keywords associated with groups A and B from various articles that examined the effects of urbanization on environmental sustainability, green infrastructure, and sustainable development. Group C search terms were also incorporated into the query to analyze the published work related to the investigation's context. Furthermore, when performing a search query in the databases, Badampudi et al. (2015) underscored that it is essential to implement the reverse snowball testing approach in the last phase of research.

As a result, we discovered five more papers through backward snowball sampling, which analyzes the bibliography of the 36 publications taken from the search query (see Figure 2). To execute the search phrase and retrieve publications related to the research importance, we employed the subsequent sources of knowledge (see Figure 2):

- ACM
- IEEE Explore
- ScienceDirect
- Emerald Insight
- SpringerLink

3.1.1.3 Inclusion and Exclusion Criteria

The criteria used to choose which articles to include and which to omit are outlined in Table 3.

Inclusion Criteria	Exclusion Criteria
Publications that discuss how urbanization affects the sustainability of the environment.	Exclude non-peer-reviewed articles
Articles on improving environmental sustainability through technological advances like AI, ICT, cloud computing, and IoT.	Articles that are not available in English.
Publicly available articles	The entire text of the article is not available
Articles from 2013 to present	Exclude duplicate papers
Articles Full text available online	Exclude short papers

Table 3 Inclusion and Exclusion Criteria

3.1.1.4 Data Extraction

Data extraction is used, and the above extraction strategies were utilized to obtain data from every article.

- Article Title

- Publication Type
- Objectives of Studies
- Research Methods
- Relevance with Research Questions
- Technology and Proposed Solution

3.1.2 Interviews

To gain a comprehensive understanding of the correlation between the influence of urbanization and environmental sustainability, we employed interviews as the qualitative method in this study. Interviews come in several forms: semi-structured, unstructured, and structured. For our research, we used semi-structured interviews as a qualitative sampling method. Semi-structured interviews are an excellent way to increase knowledge and obtain insightful information (Chen & Reeves, 2019; Denscombe, 2018). Semi-structured interviews allow the researcher to prepare an essential list of questions relevant to the study and intend to get deep responses through casual talks with the interview subjects (Adeoye-Olatunde & Olenik, 2021). The authors formulated the key questions to provide a means of delving into many avenues of discussion. Interview responses may inspire inquiries that cannot be anticipated (Oates et al., 2022). One-on-one interviews will be carried out to provide the investigator with a more thorough understanding of complex contexts. To give individuals freedom and ease, interviews are conducted using conventional in-person approaches and contemporary digital platforms like Teams or Zoom. These semi-structured interviews are effective for getting detailed information from respondents for evaluation. If the people being interviewed agree, these interviews will be audio-recorded and subsequently transcribed.

3.1.2.1 Interview Questions Creation and Methods of Sampling

It was vital to prepare interview questions according to the researchers' comprehension after reviewing several theoretical models of monitoring the effect of urbanization on environmental sustainability through modern technology before performing semi-structured interviews to obtain evidence for this study. The investigator adhered to the Laryeafio and Ogbewe (2023) established categories of interview questions by starting with basic inquiries and moving on to further executing concerns. There are numerous approaches for selecting study participants for a sample. To get input from knowledgeable individuals who can help address the research topic in greater depth, the researchers in this study used a straightforward random sampling technique. Researchers selected these individuals based on their contributions to formulating and applying urban development and environmental sustainability policies. The researcher emails the parties directly involved in environmental sustainability and requests an interview (see Appendix I) based on the abovementioned specifications. Those who accepted the invitation for interviews had characteristics mentioned in Table 4.

Participant	Gender	Age	Employment	Nationality
P1	M	A1	Senior Environmental Strategist	Sweden
P2	M	A2	Strategic Planning	Sweden
P3	F	A3	Project Research Officer	Sweden
P4	M	A4	Environmental Department	Sweden

P5	M	A5	Municipality Office	Pakistan
P6	M	A6	Strategic Department	Sweden

Table 4 Respondent Characteristics

3.1.2.2 Interview Guide

The authors created an interview guide to generate the interview questions. The interview guide comprises a total of 22 questions. The entire interview guide, including question sections and phases, is in Table 5. During the first phase of the interview, we introduce the project and ourselves. During this stage, we establish a shared understanding. We then go on to the second phase, discussing more detailed ideas of urbanization and sustainability after discussing the broad themes. Following that, we discussed their current procedures and policies in the practice phase to ascertain the necessity of environmental sustainability. During the thinking phase, we discussed the possibilities of technology and how we may employ new developments to support environmental sustainability. We show them our prototype at the end of the last phase to receive their final opinions based on the entire conversation. Ultimately, we conducted six online interviews with various stakeholders. The shortest interview was forty minutes, and the longest was an hour.

Phases	Questions
Warm Up	<ul style="list-style-type: none"> • Hello! • Could we record this meeting for our record? • Please introduce yourself. • Which company do you work for right now? • Could you briefly overview your background and position within environmental sustainability initiatives? • How do you define urbanization?
Ease Up	<ul style="list-style-type: none"> • What should be the top goals for municipalities and planners when it comes to encouraging environmental sustainability? • How do you envision the connection between environmental sustainability and urbanization changing in the coming years? • What are the biggest issues with environmental sustainability that cities are currently facing?
Practice Phase	<ul style="list-style-type: none"> • What effects do current laws and rules have on attempts to promote environmental sustainability and urban development? • Which digital technologies do you now employ to monitor the environment? • Do you collaborate with any tech companies to improve sustainability in the environment? • What adjustments or enhancements to existing strategies are necessary to effectively handle sustainability issues? • How do you include local organizations in urban sustainability initiatives? • How does urbanization affect the sustainability of the environment?

	<ul style="list-style-type: none"> • Which measurements or indicators are used to evaluate the success of sustainability projects? • What part, in your opinion, does technology contribute to establishing plans for sustainable urban development?
Thinking Phase	<ul style="list-style-type: none"> • What are the key advantages and drawbacks of utilizing technology to encourage environmental sustainability in cities? • How do you see digital technology being integrated into the management of cities in the future to address sustainability concerns? • What do you think the future holds for environmentally sustainable urban growth? • Which innovations or themes do you think will influence this sector's future? • How do you think technology breakthroughs, such as smart city solutions or IoT devices, are being applied to improve environmental sustainability in urban centers?
Wrap Up	<ul style="list-style-type: none"> • Do you have any more to say on this subject or any closing remarks you'd want to share? • Presenting Prototype

Table 5 Interview Guide

3.1.3 Experiment

According to Denscombe (2018), an experiment is a scientific inquiry examining the characteristics and connections among particular elements. An experiment aims to focus on specific variables and closely examine their impact. The goal is to evaluate hypotheses or find unexpected connections related to the items under investigation. As Pandey and Pandey (2021) mentioned in the experiment, the investigator aims to examine anything unique by using an orderly and rational strategy to address the concerns. Using this approach, we can investigate how a single independent variable affects a dependent variable. Moreover, the investigator must assume that the study settings were completely novel during the experiment because they had not been present before.

By reviewing the literature, we found that emerging technology has the potential to reduce the impact of urbanization and increase overall sustainability. However, prior studies primarily focus on utilizing the statistical and theoretical approach to evaluate urbanization impact without describing how we can utilize emerging technology practically in natural settings. Therefore, we conducted a practical experiment with the help of our developed IoT-based tool to answer our second research question. The experiment aims to analyze the toolkit's effectiveness in an authentic setting. Moreover, we want to explore the potential of emerging technology and how we can develop and utilize such tools in practice to improve sustainability in urban areas. For this purpose, we utilize two IoT-based toolkits to measure different environmental factors that compromise the sustainability of the environment due to urbanization.

There is no difference between Toolkit 1 and Toolkit 2 because we designed both using the same hardware and software components mentioned in section 3.1.4.2. Our designed kit can measure environmental metrics such as CO₂, Temperature, eCO₂, Humidity, and TVOC. We conducted four different experiments in different locations to

collect the data on the above-mentioned environmental metrics. Both devices can receive data about the mentioned environmental metrics from different sensors and store this data for later evaluation and decision-making. The collected data provide information about the environmental conditions to see the trends and variations in different periods.

3.1.3.1 Experiment 1

In this experiment, we placed our first IoT-based toolkit in the Värnhem Malmö public bus stop, as shown in Figure 3. This experiment aims to analyze whether the data we received from this device is appropriate.



Figure 3: Deployment of Toolkit 1 in Värnhem Bus Stop

3.1.3.2 Experiment 2

In this experiment, we placed both toolkits in similar places in Södervärn Malmö, as shown in Figure 4. We did this to contrast the toolkits and analyze their accuracy and effectiveness.



Figure 4: Both toolkits were placed in similar places

3.1.3.3 Experiment 3

In our third experiment, we placed our toolkits in two different locations in Malmö City. The first location is outside Malmö Central Station, and the second is Malmö Triangeln. We chose those two locations because they have a lot of traffic, restaurants, shopping

areas, and people. Figure 5 shows the location of the first toolkit in Malmö central station, and Figure 6 shows the second toolkit in Trianglen.



Figure 5: Toolkit 1 Malmö C



Figure 6: Toolkit 2 Trianglen

3.1.3.4 Experiment 4

We conducted this experiment to measure the environmental metrics in a construction area. We placed our toolkit in a construction area in Malmö Östervärn, as shown in Figure 7.



Figure 7: Construction area in Malmö Östervärn

After placing these toolkits in different locations to measure the above-mentioned environmental metrics, these devices gathered the data from sensors every fifteen minutes. The data we collected from our toolkits were directly sent to our Jupyter

Notebook Cheat Sheet and saved in a CSV format. After receiving all the data, we visualize each environmental metric using Jupyter Notebook to understand it better.

3.1.4 Design and Implementation of Toolkit

3.1.4.1 Hardware Design

- **Microcontroller**

The core component of our toolkit is an Arduino UNO microcontroller, which serves as the primary working engine. It communicates with the sensor chip at the input to obtain values. The system monitors CO₂, temperature, humidity, eCO₂, and TVOC. Therefore, three separate sensors are used for these purposes because the Arduino UNO microcontroller is inexpensive, simple to use, and practical, so it fits our needs well. You can find the Arduino UNO microcontroller, which powers our system, in (Appendix II). This controller is based on ATMEGA 328P.

The Arduino UNO has six analog pins, a USB port, a power connector, and fourteen digital pins for input and output. It is capable of being run on a battery. It can be programmed with the Arduino Integrated Development Environment (Banzi & Shiloh, 2022).

- **Sensors**

DHT11 Sensor

We chose the DHT11 sensor since it measures temperature and humidity simultaneously, and we prefer a single sensor for both measurements rather than separate ones for each. Its measurement limits are 0 to 50^o C for temperature and 20 to 80% for humidity, with a precision of 5%. DHT11 operates within a voltage range of 3.5V to 5.5V. The DHT11 sensor we utilized for our research can be found in (Appendix II).

MQ-135 Sensor

To measure the level of CO₂ in the atmosphere, we use the MQ-135 sensor in our study. With a 5V power source, it measures CO₂ in the range of 10 to 2000 ppm and provides higher-quality readings in the -10 to 50^oC temperature range, as seen in (Appendix II).

Adafruit SGP30 Sensor

The Adafruit SGP30 TVOC/eCO₂ Gas sensor is the third sensor we use to measure air quality; with a power supply of 1.62V to 1.98V, it can measure eCO₂ from 400ppm to 60000ppm and TVOC from 0ppb to 60000ppb. Between -40 and 85^o C is the ideal temperature range for optimum results. The Adafruit SGP30 sensor we used in this study can be found in (Appendix II).

Adafruit SSD1351 display

To ensure that our device is properly working and will get values from our sensors, we use Adafruit SSD1351 OLED colour display for convenience can be found in (Appendix II).

3.1.4.2 Software Design

We utilize Arduino IDE to read data from the sensors continuously. Using a USB serial port (COM11), we transfer all the data to the Jupyter Notebook Cheat Sheet, store it in a CSV file format, and visualize that data using Python libraries such as pandas, pyserial, etc. See the block picture of the toolkit in Figure 8.

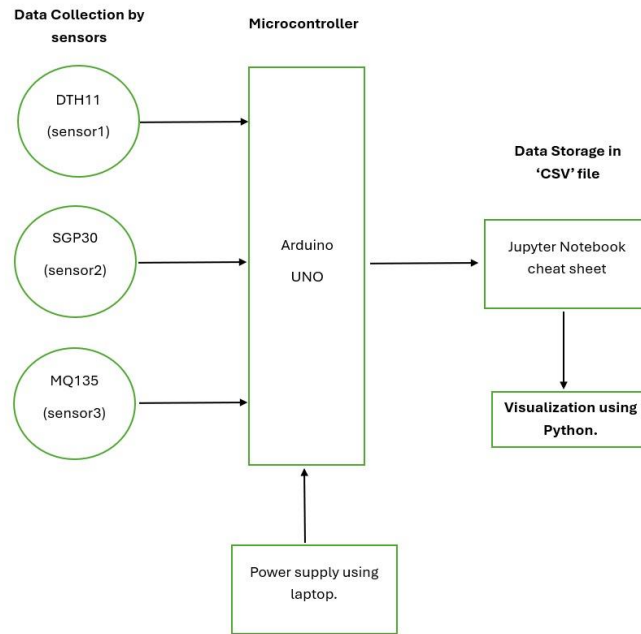


Figure 8: Block Diagram of the Toolkit

We utilize our developed IoT-based toolkit to evaluate the impact of urbanization on different environmental factors that can compromise environmental sustainability. This toolkit consists of three different sensors powered by a USB connection, which measure CO₂, Temperature, Humidity, eCO₂, and TVOC, as shown in Figure 9.

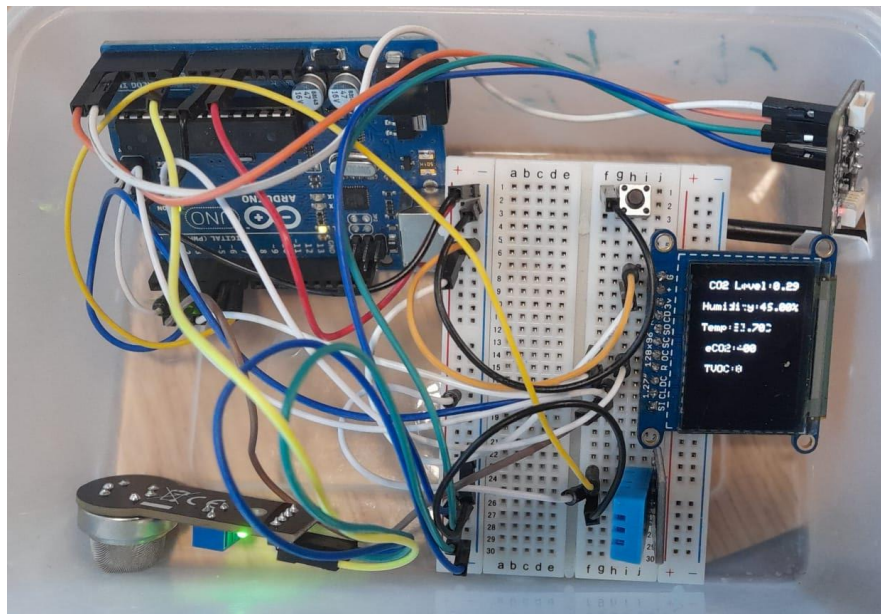


Figure 9: Hardware implementation of Toolkit Design

We utilize a USB cord attached to our laptop to power the toolkit and share sensory data. Furthermore, our laptop has a 52645mWh battery lasting about nine to ten hours. As a result, to assess the effectiveness and dependability of the toolkit, we only ran all of our trials for four hours at a time. Because the initial measurement is visible on the display screen, the toolkit is incredibly user-friendly and does not cost much. Furthermore, using this toolkit to operate and visualize the data does not require high technical experience. Although the toolkit is still in its early stages, it provides ease of portability by connecting directly to the laptop. It can readily expand to monitor several locations by integrating numerous sensors in different environmental circumstances.

3.2 Ethical Consideration

Data collection for study endeavors may impact the community. Therefore, it is essential to evaluate ethical issues. As a result, Laryeafio and Ogbewe (2023) clarified several ethical concerns. Because of this, the researcher must consider morality regarding the participants and the scenario being studied. Thus, we made the following ethical considerations in this research.

- **Privacy and data protection**

According to Creswell & Creswell (2017), an investigator must ensure that any personal or highly confidential information is hidden and protected. Additionally, we ensured that no information allowed individuals to be identified was provided. We ensured that identifiable data, such as initials, contact information, or national ID, was not utilized to protect the study respondents' confidentiality.

- **Transparency**

Be forthright and truthful about research goals, methods, and findings. Inform the participants about the limitations and possible benefits of study ideas.

- **Professional Integrity**

Throughout the research process, uphold the highest norms for ethical integrity. Authors should still present study results honestly, even if they contradict the original research objectives.

- **Informed Consent**

The authors provided adequate knowledge to those participating in this study. They were expressly requested to provide their permission to record the interview for scientific analysis (see Appendix III).

- **Participation voluntarily**

The authors gave the participants of this study the option to choose whether to participate in the research project. Researchers also informed the participants that they could leave the study at any time, and if they withdrew their consent, their data would be removed.

3.3 Validity Threats

The study's validity is essential to ensure its reliability and standards. As mentioned by Oates et al. (2022), different approaches can be used to analyze the research, namely dependability, which regulates the outcome of research. Transferability refers to utilizing the research results in different contexts. Confirmability donates what was discovered by research, and credibility indicates trust in research results.

In this study, researchers utilize the member-checking method to enhance the research credibility and to lower the chances of biases Oates et al. (2022). To ensure this, we share our work with our peers and supervisor to review, which will ensure the credibility of our work. Moreover, to ensure transferability, we did different experiments to see whether the findings of this research were applicable in different settings. In addition, to enhance the reliability of this research, we utilize different approaches to select the relevant articles related to our research with the help of a combination of keywords and databases. Furthermore, the authors also conduct the reverse snowball testing approach in the articles' references list to reduce the likelihood that studies may be missed.

4 Results

4.1 Literature Results

Reviewing the literature, the authors found many existing tools to monitor environmental conditions. Using an LPCC2148 microcontroller, Ram and Guptas (2016) created a system to track the weather for a specific location. Temperature, CO₂, relative humidity, and light intensity are the four characteristics that their technology can measure. Hassan et al. (2020) unveiled a novel IoT-based architecture that uses DTH22 to monitor temperature and humidity and MQ2, MQ4, and MQ135 to detect various gases.

Additionally, the system uses an API key to transfer the gathered data to the terminal, visualized on the Thingspeak website. Kim et al. (2017) designed a system that uses an LTE connection to analyze several environmental parameters, including temperature, humidity, CO, and NO₂. Employing an Arduino Uno R3, Fuertes et al. (2015) created an affordable ecological monitoring system. Their system consists of three sensors that allow the device to detect CO, CO₂, and dust. Hareva and Marsyaf (2019) suggest utilizing the MQ-135 sensor in campus settings to check solely the air quality. Every five minutes, their device transmits air quality data stored in a MySQL database.

Furthermore, many commercially available devices, including VINDSTYRKA by IKEA, can monitor air quality. This intelligent air quality sensor can measure Temperature, Humidity, TVOC, and other PM_{2.5} in home settings, as shown in Figure 10. This device helps you monitor air quality in the IKEA smart home app.



Figure 10: VINDSTYRKA a Smart Air Quality Sensor by IKEA

Source – (Vindstyrka, Air Quality Sensor, SMART - IKEA Sweden, NA)

Another device introduced by Vaisala can measure CO₂, humidity, and temperature with the CARBOCAP sensor, as shown in Figure 11.



Figure 11: Vaisala Intelligent Measurement Module

Source – (CO2, temperature and humidity transmitter series GMW90, 2024)



Figure 12: Purple Air Classic Air Quality Monitor

Source – (Purpleair Classic Air Quality Monitor, 2024)

The initially introduced and well-known Purpleair detector is the PurpleAir Classic air quality analyzer. It can be utilized indoors or outdoors to monitor PM2.5 levels for home, commercial, or workplace use, as shown in Figure 12.

Toolkits	Academic Toolkit	Commercially Indoor toolkit	Commercially Outdoor toolkit	Measurements
-----------------	-------------------------	------------------------------------	-------------------------------------	---------------------

Ram and Guptas (2016)	Yes			Temperature, CO2, Humidity, and Light Intensity
Hassan et al (2020)	Yes			Temperature, Humidity, and CO2
Kim et al (2017)	Yes			Temperature, Humidity, CO, and NO2
Fuertes et al (2015)	Yes			CO, CO2, and Dust
Hareva and Marsyaf (2019)	Yes			Air quality
VINDSTYRKA By IKEA		Yes		Temperature, Humidity, TVOC, and PM2.5
Vaisala with CARBOCAP sensor		Yes		CO2, Humidity and Temperature
Purpleair Classic Air Quality Monitor		Yes	Yes	Pressure, Temperature, Humidity, PM1.0 and PM2.5
IQAir AirVisual Pro		Yes	Yes	Pressure, Temperature, Humidity, CO2, PM1, PM2.5 and PM10
Vantage Vue		Yes	Yes	Temperature, Humidity, Barometric Pressure, Wind speed and Rainfall

Table 6: Existing Academic and Commercially Tool

As shown in Table 6, academic and commercial devices mentioned above are more suitable for indoor and outdoor settings. Moreover, numerous IoT-based systems are available to track various environmental variables. The devices use different sensors, platforms, and connectivity technologies and are suitable for multiple situations.

4.2 Interview Results

4.2.1 Thematic Analysis

In qualitative studies, researchers mainly use thematic analysis (TA) to analyze the data (Kiger & Varpio, 2020). TA is a technique for finding and examining exciting patterns and themes in qualitative data that foster the objective of our research (Clarke & Braun, 2017). This study used the Kiger and Varpio (2020) thematic analysis strategy. This strategy has six stages, which are listed below.

- Become familiar with the information.
- Generating initial codes
- Searching for themes
- Reviewing themes
- Defining and naming themes
- Producing scripts

Therefore, we started the thematic analysis by transcribing all the audio recordings of interviews. After transcribing all interviews, we began to read each interview's transcription to familiarize ourselves with the data and identify initial data assign codes (see Appendix IV). This study used concept-driven coding and generated themes for analysis.

4.2.2 Themes

After talking with all the interviewees and obtaining permission to record their sessions, we conducted all the interviews online via Zoom. We recorded all the interviews using the built-in recording function in Zoom. Each interview took roughly forty minutes to one hour on average. To transcribe all the interviews and generate themes, we used otter.ai transcription software and transcribed all six interviews. The software was selected because of its open privacy policy and reasonable accuracy rate. Otter does not disclose registration data to third parties and abides by stringent confidentiality regulations. These interviews help us to generate themes for the analysis of this study. The following sections mention the themes generated from the interviews.

4.2.2.1 Information about Urbanization

All the members who participated in the interviews knew about urbanization and environmental sustainability. They all described urbanization as moving people from rural areas to cities for a better living experience. Moreover, all the participants have prior experience in environmental planning and urban planning to mitigate the impacts of urbanization. P1 has worked as an environmental strategist in Sweden for almost 38 years. P2, P3, and P4 have worked in the environmental department for over 20 years. P5, whom we interviewed, worked in a municipal office in Pakistan and was aware of the issues related to urbanization. In addition, P6 works in Malmö municipality, focusing on constructing parks and green spaces in residential areas to promote sustainability in urban centers. Further, P2 and P3 describe the increasing population in most of the world, specifically Malmö. Therefore, city planning is essential because putting homes, schools, and daycare centers for children close to emission sources is terrible in the long run.

4.2.2.2 Understanding Environmental Sustainability

To know about each contest's point of view on the importance of environmental sustainability. We asked participants how they perceive environmental sustainability in

an era of rapid urbanization. Environmental sustainability is like reducing the effect of climate change and maximizing resource usage for all participants. Environmental sustainability is the management of environmental policies and strategies (P3). P4 perceived environmental sustainability by having access to green spaces in urban centers to improve air quality and mitigate the effects of urban heat. However, P1 mentioned that using renewable energy sources contributes to environmental sustainability.

P6 is also in line with P4 and mentioned that they are currently working on an initiative where each person can see at least three trees from their window and access parks within 300 meters from their residence. Moreover, he stated that green infrastructure covers thirty percent of the land, but in Malmö, only 14 percent is used for green spaces. All the participants generally perceived access to urban green spaces, utilization of sustainable resources, and management of environmental policies as essential to reducing carbon emissions in the atmosphere, improving air quality, and promoting sustainability.

In addition, P2 mentioned that to select the best species for greenery in cities, they consult with experts at SLU University and Malmö Urban Living Lab, who are responsible for experimenting with which species of trees are good enough for Malmö. P2 and P4 commented that green spaces in public spaces can reduce the UHI impact. Also, the CO₂ emissions noise pollutions those things. One participant noted that his understanding of environmental sustainability changed after moving from his native country, which led the researcher to conclude that culture matters regarding environmental sustainability.

P5 responded to the investigator's question: "In the country where I come from, we are not concerned with the sort of environmental sustainability problems that European nations are worried about right now." He said, "SDG goals are one thing that has influenced my perspective of environmental sustainability." Though much remains to be done, the situation appears to be improving. On the other hand, I believe that this environmental policy is now the strongest available worldwide (P5). Moreover, (P5) said that environmental sustainability is unimportant in his nation. However, I soon discover that things are very different in Europe. People are aware of sustainability, care about it, and act to advance it.

4.2.2.3 Impact of Urbanization

Every participant accepted that urbanization is one of the rising issues of the present day. P1 described that rapid urbanization can affect the sustainability of the environment. He discussed the experience he had learned from the history of Malmö that has formed the city as it is today. Malmö has gone through many ups and downs in the transformation. From the beginning, we used to be a fishing village, and then we were like a Trade Centre in the Hanseatic system. In the 1960s, Malmö was one of Sweden's wealthiest towns or municipalities or cities in Sweden. We have a 3 kronor lower local income tax than the average in Sweden. In the early 1980s, Malmö started to have many problems because of the economic crisis in Sweden, and we lost many jobs due to rapid urbanization. However, it is not the same now because Malmö is a growing city in Sweden. Thirty years ago, Malmö faced many environmental problems, including air pollution and poor water quality. We have now developed a new version of Malmö, the Smart ecological city of tomorrow. We have the best farmland in the northern part of Europe. So, we also have the challenge to protect our excellent farmland.

P2, P3, P4, and P6 also mentioned that Malmö has many farmlands and land degradation occurs due to rapid urbanization. Hence, we must consider how to protect those lands to produce quality food. P1 said we must balance the economy because of land degradation and fill that land with new soil. P5 commented that we need to consider the consequences of urbanization because it increases the demand for resources, and unplanned urbanization harms the environment. It produces more emissions in the air and badly affects natural resources.

Water Quality and Management

P1, P2, P3, P4, and P6 mentioned their ambition is to be climate-neutral until 2030. They are currently working with the production of heavy energy using solar and wind to produce local climate-smart electricity and heat. We have effective systems for cleaning water and water supply. P1 commented that the one significant initiative they are currently doing in Malmö and the whole region is to take all the wastewater from the municipality of Lund and other surrounding municipalities clean in Malmö and release it into the sea directly instead of polluting small creeks. They are making a big tunnel in Malmö to clean wastewater and store it for reuse to avoid water secrecy problems.

Moreover, P2, P3, and P6 mentioned that they are working with VASYD, responsible for ensuring water supply and quality. They also visualize the utilization of water consumption and streamline it for their customers. P5 mentioned that they are now in the early stages of this initiative, and it is good to think about the storage and recycling of water to meet the present and future needs.

Green Infrastructure and UHI

To know how participants perceive green infrastructure in an era of rapid urbanization to foster environmental sustainability. Most participants believe green infrastructure is crucial for improving environmental quality, particularly in metropolitan areas. P1 commented that one thing that we are working on a lot now or have done for many years is to have more trees in Malmö to foster sustainability and to reduce the impact of increased urbanization as Malmö is one of the growing cities in Sweden. P2, P3, and P4 mentioned that they faced heat waves, heavy rains, and flooding, so green infrastructure plays a crucial role in controlling those effects. P5 and P6 commented that green infrastructure reduces UHI's impact and fosters air quality in urban areas.

Land Degradation

Every participant holds the belief that because of urbanization, there is a decrease in arable land and consequent land degradation. P3 commented that this is a crucial idea and that we should consider long-term ways to save agricultural land. P6 stated that there has been a significant decrease in the quantity of farmland due to rising urbanization. Furthermore, he stated that to avoid future food shortages, we must adhere to the rule that no agricultural area should be sacrificed for urban growth. P6 pointed out that constructing new homes also contributes to environmental degradation. Thus, the government should enact laws to safeguard farmlands, as these are among the world's best and most productive outside of Malmö.

Air Pollution

When discussing the effects of urbanization on air quality, P1 mentioned that Malmo had poor air quality in the early 1990s because of industrial plots. Many people flee the city because of the poor quality of the air and water, which is one of the numerous issues the

city faces. P2 added that he works closely with both noise and air pollution. He went on to say that technology is to blame for noise pollution.

It has benefits as well as occasional drawbacks. Cars take up areas that could be utilized for other purposes, resulting in several issues with air quality and noise. P5 stated that there is a direct correlation between urbanization and air quality. Because more people live in cities, they use more resources, and there are not enough rules to address these problems, leading to increased atmospheric emissions and a rise in temperature brought on by human activity.

4.2.2.4 Technology Adaptation and Climate Change

Discuss how technology can improve resource management, urban planning, and environmental sustainability. Many study participants stated that they are measuring the impact of urbanization by utilizing new technologies. Most respondents claimed that promoting sustainability in urban settings using digital technology was the only effective strategy for mitigating the effects of urbanization. P1 mentioned that they had already used smart technology to improve Malmö City.

He further mentioned that they are working with climate-smart technologies such as radar to monitor sea levels and predict the probability of floods and rains. He further commented that they also work with some sensors to monitor the air quality in Malmö so they can get data. This system can measure environmental conditions like temperature, noise, and carbon emissions. It consistently measures those indicators around the clock and helps municipalities to improve air quality. We have another kind of challenge about making things sustainable, but that is also an advantage; we would have this more dense city because we could have adequate systems for transportation, buses, and trains, for example.

P2, P3, and P4 emphasized the existing models for monitoring environmental noise and air quality. They were concerned about the accuracy of sensor data because it is much more difficult to check its quality. Further, they expressed that they have started an initiative to take temperature sensor data to give warnings and monitor elderly health, which costs almost 1.5M SEK. With this sensor data, we can determine what buildings are more vulnerable to higher temperatures. In addition, they mentioned that it is challenging to get sensor data from people's homes because of legal issues, so adoption is also a challenge in monitoring the elderly.

P6 is more interested in using innovative technology, including geographic information systems and remote sensing, to get spatial information about the land and to choose good places for parks and urban greenery. P5 also discusses monitoring environmental factors through intelligent technology to control the impact of urbanization and ensure sustainability. Furthermore, he mentioned that they utilized little innovative technology to evaluate the impact of urbanization on their city, but it could be possible in the future. Moreover, P1, P2, P3, P4, and 6 stated that they used innovative technology in all their practices to reduce the impact of climate change. They produce energy through renewable resources. They used green technology that has less impact on the environment. All the participants generally accepted that utilizing emerging technologies is essential to ensure sustainability in urban areas. Furthermore, they expressed that they followed the Översiktsplan för Malmö 2023 and the environmental program for the city of Malmö in which they describe their practices to promote sustainability.

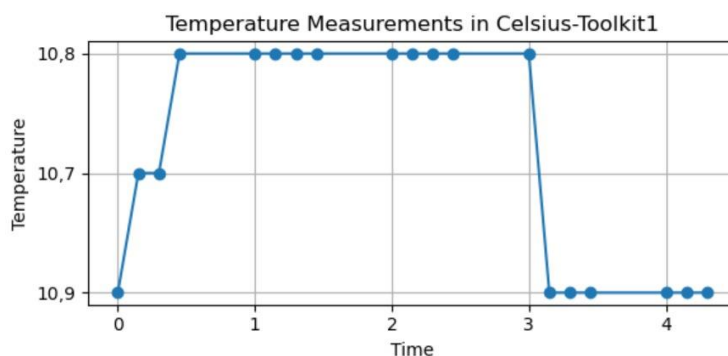


Figure 14: Temperature in Celsius by Toolkit 1

Our toolkit indicated a temperature reading between 10.7 and 10.9 degrees when we conducted our first experiment, as shown in Figure 14 in Värnhem Malmö. In the first hour, the temperature slightly changes between 10.9 to 10.8. Moreover, the temperature remains constant at 10.8 in the next two hours, but in the last hour, it slightly increases from 10.8 to 10.9. Furthermore, our mobile weather app showed that the temperature in Malmö is between 5 to 6 degrees; maybe our toolkit is enclosed in an airtight box and getting warm with other sensors.

Figure 15 illustrates the assessment of humidity from Toolkit 1 in Värnhem.

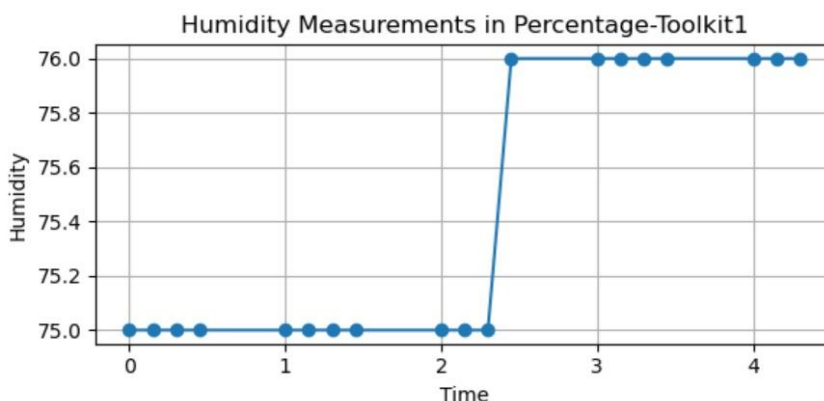


Figure 15: Humidity in percentage by Toolkit 1

Moreover, as shown in Figure 15, the humidity level was stable for the first two hours at 75%, which is similar to our mobile weather app's indication of 73%. But in the last two hours, it slightly changed from 75% to 76% and remained constant.

Figure 16 illustrates the assessment of eCO2 from Toolkit 1 in Värnhem.

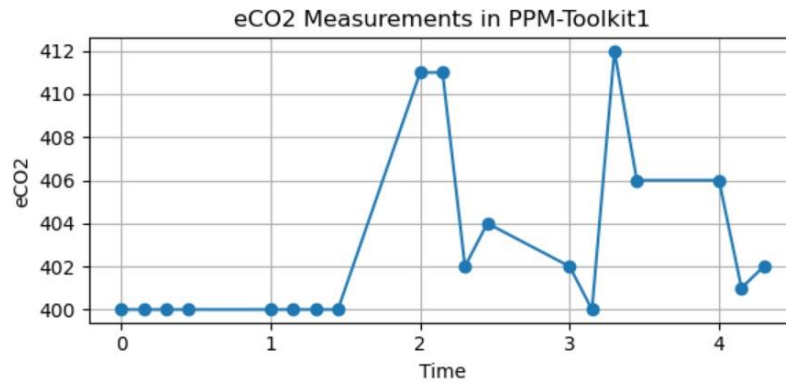


Figure 16: eCO2 in PPM by Toolkit 1

We observed that the value of eCO2 is stable in the first 1.5 hrs at a value of 400 ppm, and then there is a steady increment from 400 ppm to 411 ppm in the next half hour, as shown in Figure 16. In the next two hours, there was a gradual decrease and increase in the value of eCO2, reaching the maximum value of 412 ppm.

Figure 17 illustrates the assessment of TVOC from Toolkit 1 in Värnhem.

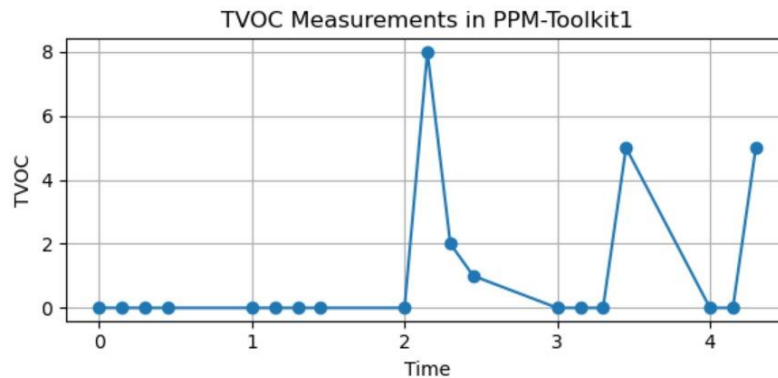


Figure 17: TVOC in PPM by Toolkit 1

The measurements of two are zero and remain constant for the first two hours. Then, at the start of the next hour, there was an increase from 0 ppm to 8 ppm, which can be found in Figure 17. After that, there is a slight decrease in the value of two between the second and third hours. At the start and end of the last hour, the values remain constant at 0. All the measurements are for four hours; therefore, there is a slight difference in values.

4.3.2 Experiment 2

This section shows the results of different environmental metrics from both toolkits that we placed in similar places in Södervärn. This toolkit was placed on Tuesday, March 19th, 2024, between 11 a.m. and 3 p.m. It collects data for four hours and updates it every fifteen minutes. Below, the visualization of Experiment 2 is available.

Figure 18 illustrates the contrast assessment between CO2 measurements of both Toolkits in the exact Södervärn location.

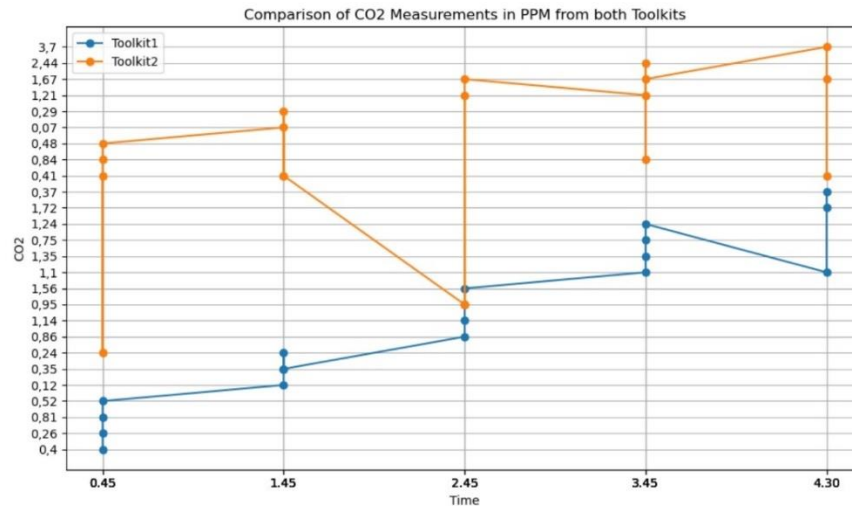


Figure 18: CO2 in PPM Contrast by both Toolkits

Experiment 2 aims to assess the accuracy of both toolkits. After evaluating the measurements of CO2 from both toolkits, Figure 18 describes that the values from both devices are similar. Toolkit 1 shows the maximum value as 1.72 ppm, whereas Toolkit 2 depicts the value as 3.7 ppm. So, both devices have lower values than the standard values for CO2. In the first hour, the values of CO2 from both toolkits were between 0.12 ppm and 0.84 ppm. In the next hour, there was a slight increase in the values of both toolkits, from 0.86 ppm to 1.67 ppm. In the last two hours, there has been a steady increase in the values from 1.72 ppm to 3.7 ppm.

Figure 19 illustrates the contrast assessment between temperature measurements of both Toolkits in the exact location in Södervärn.

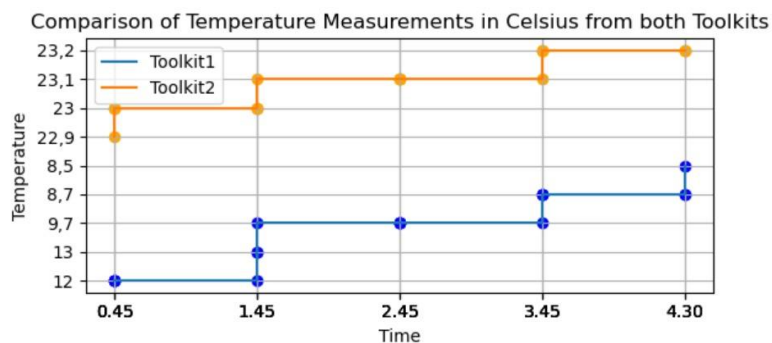


Figure 19: Contrast in Measurement of Temperature in Celsius by both Toolkits

After that, we compared the temperature values and figured out that in the first hour and forty-five minutes, Toolkit 1's temperature value was different from that of Toolkit 2, which does not align with the values shown in our weather app. The value we get from Toolkit 1 is similar to the weather app, but Toolkit 2 had high-temperature values for four hours, as shown in Figure 19.

Figure 20 illustrates the contrast assessment between humidity measurements of both Toolkits in the exact location in Södervärn.

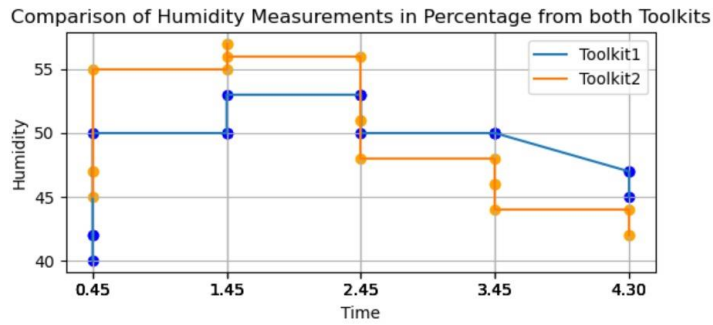


Figure 20: Contrast in Measurement of Humidity in percentage by both Toolkits

In addition, Figure 20 shows that the humidity values from both toolkits are similar, indicating the effectiveness of humidity sensors. There is a slight increase and decrease over time, but the values are in line with a mobile weather app that shows the accuracy of sensors.

Figure 21 illustrates the contrast assessment between eCO2 measurements of both Toolkits in the exact Södervärn location.

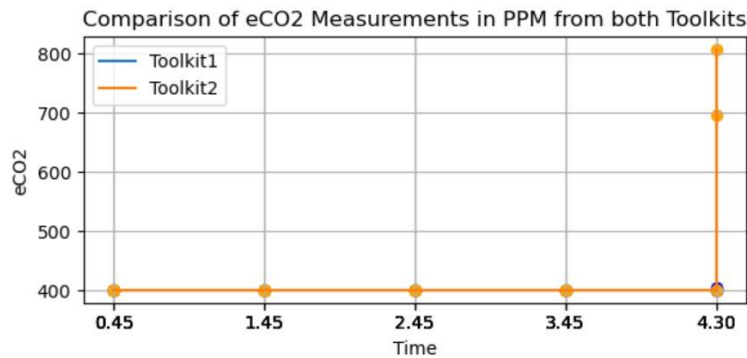


Figure 21: Contrast in Measurement of eCO2 in PPM by both Toolkits

Furthermore, the eCO2 values from both devices are the same and follow the same pattern for almost 3.5 hours (see Figure 21), and then there is a sudden increase in Toolkit 2 from 400 ppm to 800 ppm. The same situation happened in the measurement of TVOC, as shown in Figure 22. We think that this happened due to several reasons, such as the low effect on both metrics in the area, unexpected shifts in the climate, and a rise in human activity.

Figure 22 illustrates the contrast assessment between TVOC measurements of both Toolkits in the exact Södervärn location.

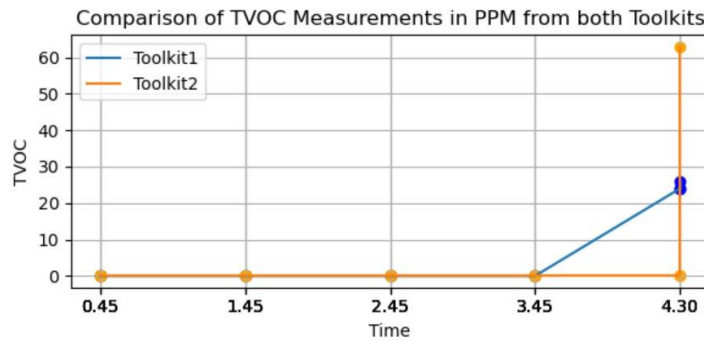


Figure 22: Contrast in Measurement of TVOC in PPM by both Toolkits

4.3.3 Experiment 3

This section shows the results of different environmental metrics from both toolkits we placed in different places. We placed the first toolkit in Malmö Central Station and the second in Triangeln. We deployed these toolkits on Wednesday, 20th March 2024, between 10 am and 2 pm and collected data continuously for four hours, updating it every fifteen minutes. Below, the visualization of Experiment 3 is provided.

Figure 23 illustrates the contrast assessment between CO2 measurements of both Toolkits in different locations.

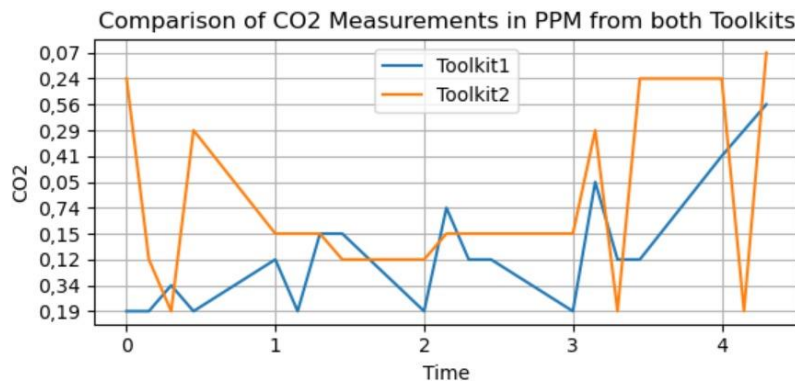


Figure 23: Measurement of CO2 in PPM by both Toolkits Placed in Different Locations

In this experiment, we placed our toolkits in different locations to see how environmental factors are different from one location to another. Furthermore, both the locations where we placed our toolkits are busy with people and much traffic, but we found less CO2 in both places; as shown in Figure 23, toolkit 1 depicts the minimum value of CO2 as 0.05 ppm and 0.74 ppm as a maximum throughout the experiment. Meanwhile, toolkit 2 shows values between 0.7 ppm and 0.29 ppm, which are lower than the standard values of CO2.

Figure 24 illustrates the contrast assessment between temperature measurements of both Toolkits placed in different locations.

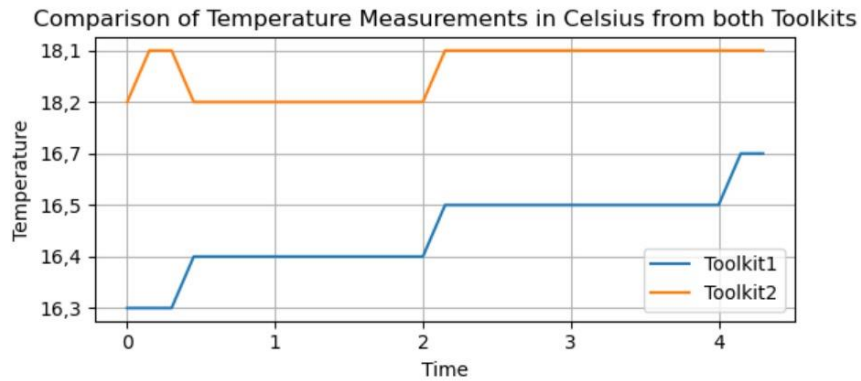


Figure 24: Measurement of Temperature in Celsius by both Toolkits Placed in Different Locations

Figure 24 shows that the temperature values from both toolkits are close to each other but do not match the values shown in the mobile weather app. Our weather app shows the temperature value of the particular day as 12° Celsius, which is because our toolkit and sensor are closed in an airtight box or getting warm from each other.

Figure 25 illustrates the contrast assessment between humidity measurements of both Toolkits in different locations.

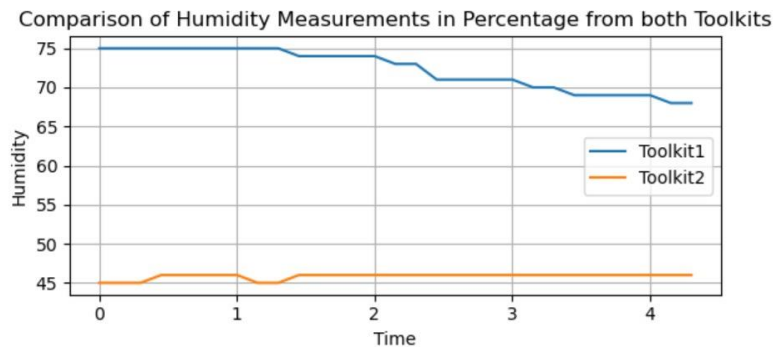


Figure 25: Measurement of Humidity in Percentage by both Toolkits Placed in Different Locations

Figure 25 shows the correlation between the humidity values of both toolkits. The values of Toolkit 1 range from 68% to 75% at the maximum. Moreover, toolkit 2 indicates values between 45% and 47% throughout the experiment.

Figure 26 illustrates the contrast assessment between eCO2 measurements of both Toolkits in different locations.

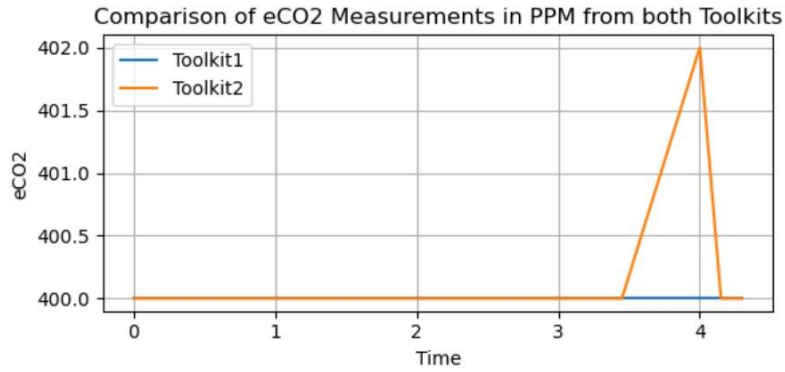


Figure 26: Measurement of eCO2 in PPM by both Toolkits Placed in Different Locations

Furthermore, Figures 26 and 27 show eCO2 and TVOC values with slight from both toolkits, especially in the last hour.

Figure 27 illustrates the contrast assessment between TVOC measurements of both Toolkits in different locations.

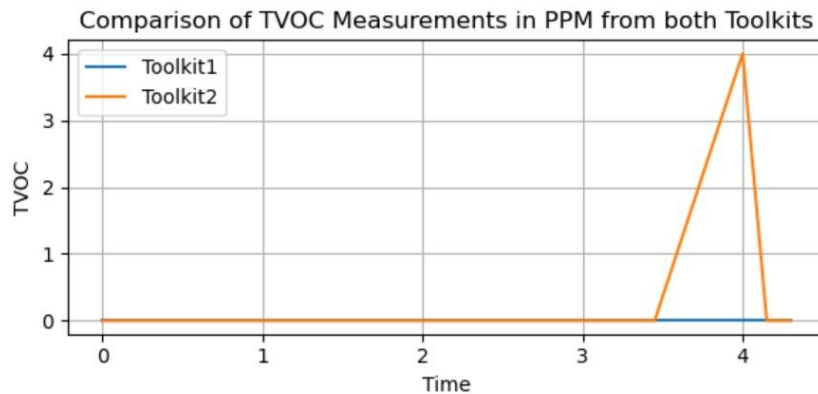


Figure 27: Measurement of TVOC in PPM by Toolkits Placed in Different Locations

4.3.4 Experiment 4

This section shows the results of different environmental metrics from our toolkit that we placed in a construction area. This toolkit was placed in Östervärn Malmö on Thursday, 21st March 2024, between 09 am and 1 pm. It constantly collects data for four hours and updates it every fifteen minutes. Below, the visualization of Experiment 4 is presented.

Figure 28 illustrates the assessment of CO2 from the Toolkit in the construction area in Östervärn.

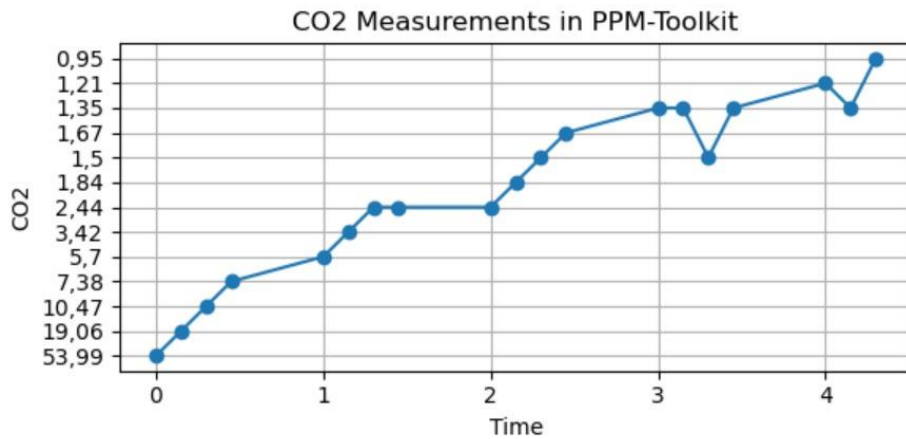


Figure 28: CO2 in PPM by Toolkit in Construction Area

This experiment aims to measure the environmental indicators in construction areas to see how they differ from other locations. Figure 28 shows that the values of CO2 in that area are more significant than those we got in other locations. The values of CO2 in that area are between 0.9 ppm and 53.99 ppm. This is because, in that location, they used much machinery for construction purposes; therefore, the value of CO2 is high compared to other locations.

Figure 29 illustrates the temperature assessment from the Toolkit in the construction area in Östervärn.

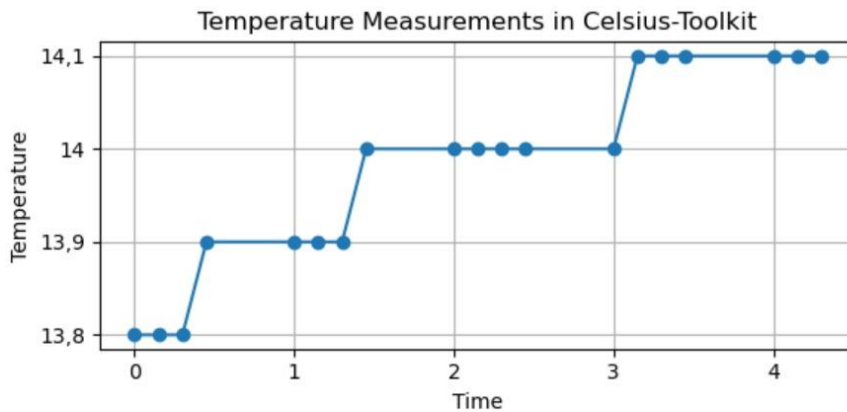


Figure 29: Temperature in Celsius by Toolkit in Construction Area

In Figure 29, the temperature value from the toolkit in the first hour is 13.8° Celsius and then slightly changed to 13.9° Celsius. Furthermore, the temperature increases every hour, reaching a maximum of 14.1° Celsius in the last hour. This time, the temperature values align with those in the mobile weather app, which are 12° Celsius.

Figure 30 illustrates the humidity assessment from the Toolkit in the construction area in Östervärn.

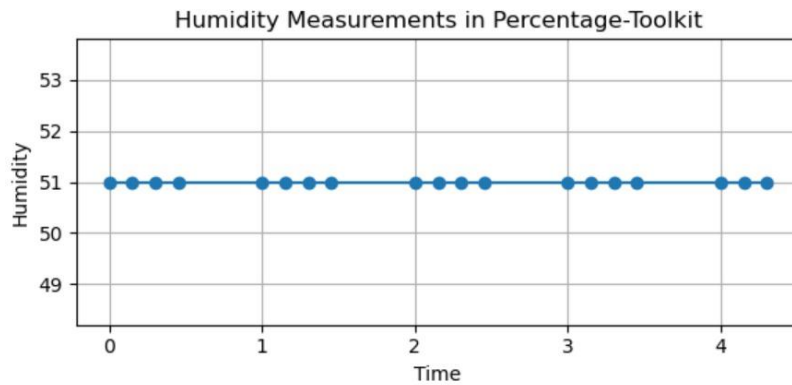


Figure 30: Humidity in Percentage by Toolkit in Construction Area

Moreover, the humidity in the construction area remained constant at 51% during the experiment, as shown in Figure 30.

Figure 31 illustrates the assessment of eCO₂ from the Toolkit in the construction area in Östervärn.

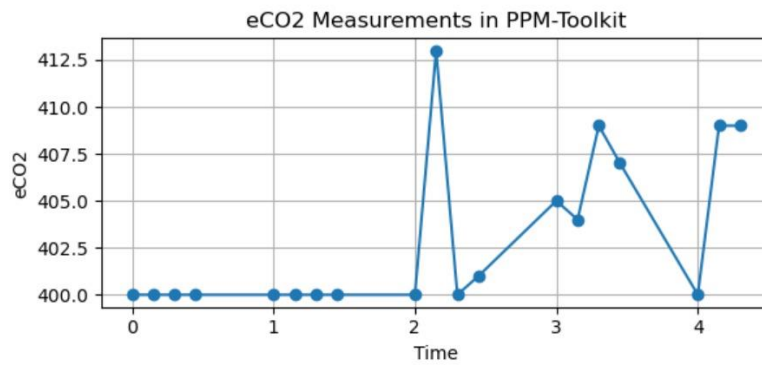


Figure 31: eCO₂ in PPM by Toolkit in Construction Area

The eCO₂ measurement in Figure 31 did not change for two hours and remained constant at 400 ppm. Moreover, in the last two hours, the values gradually increased and reached a maximum of 412.5 ppm. The same thing happened to the two values. They remained constant for the first two hours and then increased in the last two hours, reaching a maximum value of 6.8 ppm, as shown in Figure 32.

Figure 32 illustrates the assessment of TVOC from the Toolkit in the construction area in Östervärn.

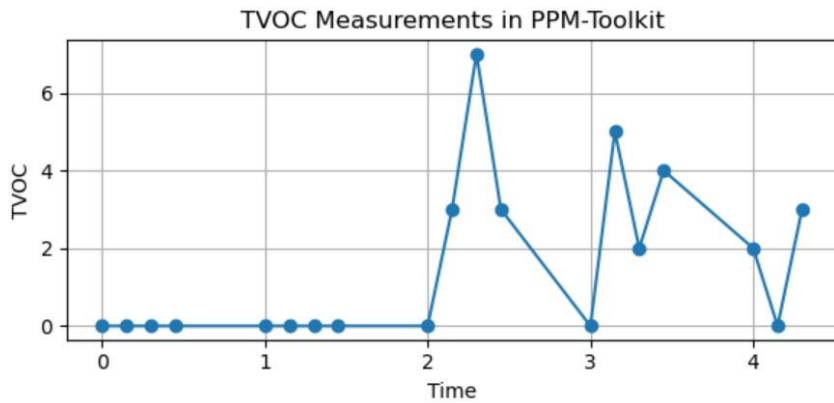


Figure 32: TVOC in PPM by Toolkit in Construction Area

After conducting all the experiments, we had doubts about the temperature sensor's accuracy because the values we received differed from those from our mobile weather app in every experiment. This discrepancy could be due to not using advanced sensors or because our toolkits were directly exposed to sunlight, which warmed up the sensor. Additionally, keeping the sensor in a box retained heat, causing it to indicate higher values than predicted by the weather app. Moreover, all the experiments lasted for four hours, and we observed that construction areas exhibited higher CO₂ emissions than other locations but lower than the standard value of CO₂. Therefore, no single environmental metrics were affected by urbanization or negatively impacted environmental sustainability. Based on the findings from the experiment, researchers noticed that integrating emerging technologies is vital in reducing the impact of urbanization.

5 Analysis and Discussion

This section aims to convey the answers to research questions. Initially, we will discuss our first research question in connection with the findings from literature and interviews, and later, we talk about the second research question concerning the results of experiments.

5.1 RQ1: How does urbanization affect various environmental metrics related to sustainability?

By reviewing the literature, we found that the increasing urbanization and environmental degradation development can create many serious problems, affect the climate, and compromise overall environmental sustainability. Our literature review found that several variables, including finance, excellent instruction, farms, professions, and others, are necessary for the globe to expand sustainably. However, environmental sustainability constitutes one of the most crucial ones. Moreover, increases in temperature due to energy consumption, carbon emission, CO₂, and other gases are the most pressing indicators that urbanization affects.

Furthermore, researchers discovered that urbanization presents several obstacles and issues for environmental sustainability after examining numerous previous studies. In addition, the many environmental metrics impacted by the fast urbanization of metropolitan areas that researchers discovered in the literature are displayed below in Table 7.

Articles	Frequency of Metrics Appearance in Literature
Hassan et al. (2020)	CO ₂ , Temperature and Pressure
Zafar et al. (2018)	Temperature and Humidity
Mois et al. (2017)	CO ₂ and Pressure
Siddiqui et al. (2022)	CO ₂ , Temperature, Humidity and Noise
Kim et al. (2017)	SO ₂ , NO ₂ , O ₃ , CO, Temperature, Humidity and PM ₁ , PM _{2.5} , PM ₁₀
Uma et al. (2017)	Temperature and Humidity
Jazavac and Tatari (2021)	CO ₂ , CO, Temperature, Humidity, Pressure and PM ₁ , PM _{2.5} , PM ₁₀
Fuertes et al. (2015)	CO ₂ and CO
Hareva and Marsyaf (2019)	CO ₂ , SO ₂ , NO ₂ , CO and PM ₁ , PM _{2.5} , PM ₁₀

Table 7: Top Environmental Metrics in Literature

Furthermore, during the communication about urbanization and its impact on environmental sustainability, the investigators discovered that all the research participants had enough knowledge about the challenges linked with urbanization. All the participants showed that these challenges could affect the sustainability of the environment. As stated, (Ullo & Sinha, 2020), three main environmental issues are the state of the air, contaminants in water, and emission harm. In addition, the participant

interview results suggest that urbanization often comes with many environmental issues, as in Table 8.

Urban Environmental Issues
Unplanned Urban Design
CO2 Emissions
Temperature
Water contamination
Noise Pollution
Land Degradation
Greenhouse Gas Emissions
Traffic Congestion
Air Pollution
Energy Consumption

Table 8: Environmental Issues with Urbanization According to Participants

The top environmental metrics we found in the literature, as mentioned in Table 7, were visualized as a pie chart in Figure 33. This Figure shows the most prevalent indicators that jeopardize environmental sustainability and strain infrastructure. The graphic below shows that, out of all measurements, urbanization has most negatively influenced temperature, humidity, and CO2. This is because there is a danger to sustainability owing to increased resource and human activity use.

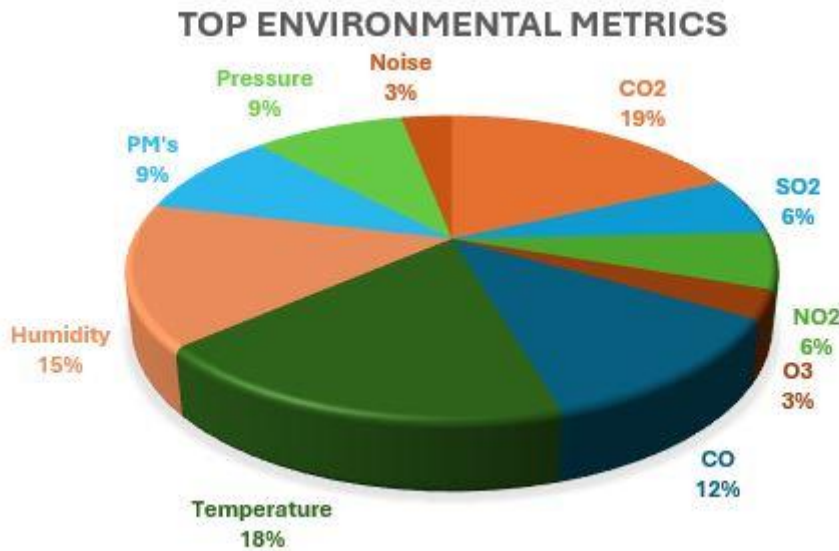


Figure 33: Metrics in Literature that Compromise Environmental Sustainability due to Urbanization

The issues emphasized by the participants, as mentioned in Table 8, relate to urbanization issues found in the literature, depicted in Figure 33. Many participants mentioned that the issue begins with the movement of people from rural to urban areas, and this rapid shift leads to many serious consequences, significantly increasing demand for resources, ultimately harming the environment. As commented by most participants, urbanization has many effects on sustainability, the environment, and human health. It

harms air quality and increases noise levels in the city because of personal vehicle usage. Due to unplanned urbanization and the need to follow the proper policies and guidelines, urbanization puts pressure on the sustainability of the environment, such as increasing temperature, releasing emissions and hazardous chemicals into the atmosphere, and burning fossil fuels.

Moreover, many participants emphasize that more than half of Malmö is the sea and has the best farmland in northern Europe; therefore, protecting both excellent farmlands and making an attractive, sustainable city for more people is challenging. Due to the increase in urbanization, there is less land for agriculture, so it is necessary to address those issues during urban planning. Participants urged that integrating emerging technologies might be an option to mitigate the impact of urbanization and promote sustainability.

In addition, throughout the interviews, we discovered that green infrastructure is one option to deal with these issues because it has a crucial role in lessening the impact of urbanization. Green spaces provide shade, improve air quality, and reduce carbon emissions in the atmosphere. Furthermore, all the participants accepted that including digital technology is crucial to evaluating urbanization's impact and promoting sustainability. As mentioned by participants, Malmö is an industrial city with many industries, so it is essential to have a balance to create a more sustainable city. Therefore, technology helps us to reduce the impacts mentioned in Tables 7 and 8 by adopting sustainable practices in urban centers.

Furthermore, we observed from our interviews that the city of Malmö follows a comprehensive plan, also known as the environmental program for sustainable development. All the participants from Sweden mentioned that this plan describes how we build a more eco-friendly city that leads to a healthier life. This plan describes their practices in developing urban environments.

By talking with all the participants, we discovered Malmö is one of the growing cities in Sweden, and they follow a comprehensive plan to achieve sustainable goals until 2030, which focuses on reducing greenhouse emissions by seventy percent, zero emissions by the organization, an excellent urban environment, rich biodiversity, and a sustainable ecosystem. Based on the interviews, the researcher realized that implementing digital technologies is vital to promoting sustainability but requires a lot of time and money. Moreover, sometimes sensory data is not good enough to make decisions, especially in a city like Malmö. The sensory data from this kind of toolkit (IoT) is excellent and implementable in developing countries where you do not know the background context of a specific area.

5.2 RQ2: How to design and integrate IoT-based tools to evaluate urbanization impact on environmental sustainability?

In the earlier section, we discussed issues related to urbanization in the literature that impact different environmental metrics that can compromise sustainability. We also discussed the insights provided by participants and their practices. After all the interviews, we discovered that Malmö had already implemented digital technology to measure air quality and noise pollution. Moreover, they also utilize the geographic

information system and remote sensing to get spatial data about land selection for green spaces.

In this section, we will discuss the results of the experiments and the practical integration of IoT tools to measure different environmental indicators impacted by urbanization. Our experiment aimed to evaluate the impact of urbanization on different environmental metrics in the city of Malmö using our developed IoT-based toolkit and implementing them in natural settings. Therefore, we conducted four experiments in Malmö to see how our developed tool measured the environmental indicators mentioned in section 3.1.3. The problem we faced during our experiment was not having access to the municipality network to send our data. Therefore, we connect our laptop to our toolkit to receive the measurement data from our sensors in our Python notebook and store this data in a CSV file format for visualization.

We received different results from our devices that show how environmental metrics are affected by urbanization. The experiments aim to determine how we can design and practically implement IoT technology and test our toolkit's potential in real-world settings to explore how emerging technology can be utilized to foster sustainability. Our experiment successfully got real-time data from different sensors that help policymakers and other government officials identify vulnerable places to do better strategic planning. Also, we discovered that using technology to monitor the environment is essential for the decision-making process. As mentioned in the literature, advancements in digital technology allow us to track the environment and forecast the impact of urbanization on environmental sustainability with the help of contemporary technology. Our experiment results found no considerable impact of urbanization on environmental sustainability in Malmö because all their sectors follow sustainable practices. So, carbon emissions and other particulate matter are very low in Malmö.

In order to promote sustainability in urban areas, we consequently suggested a design framework for a tool that would assess the effects of urbanization. The suggested design can simultaneously monitor emissions from various sectors, including the transportation and industrial sectors, residential buildings, particle gases and atmospheric emissions, water pollution, and remote sensing-based spatial data collecting for green areas. Every piece of data travels to the cloud via a network of sensors. Following that, an analytics approach will be applied to all the data to uncover patterns and trends related to urban environmental conditions. In addition, various artificial intelligence algorithms are trained on the processed data to predict the effects of urbanization if something occurs or changes in urban centers. Additionally, the findings add to the body of research already in existence, and the suggested design framework enables government authorities to obtain current environmental data via technology. The suggested design framework is depicted in Figure 34 below.

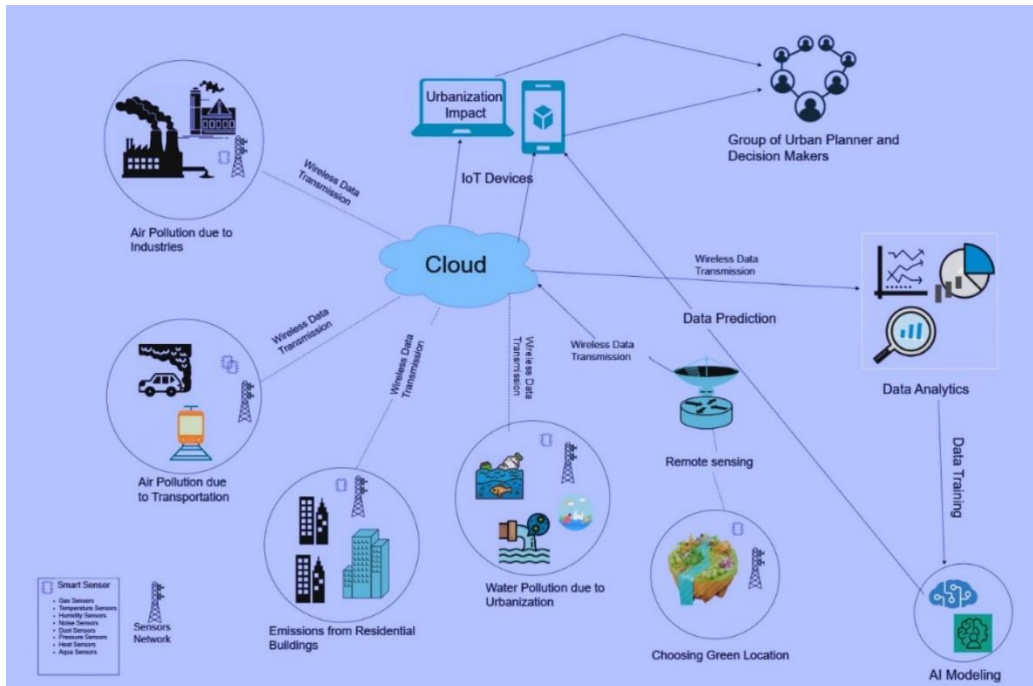


Figure 34: Proposed Design Framework to Evaluate the Impact of Urbanization on Environmental Sustainability

The design mentioned above framework can be implemented in city planning to gain insights into the specific environmental context and create more sustainable societies. Moreover, higher authorities responsible for urban sustainability initiatives and development can utilize this framework in their practices. They gain valuable insights from this study on implementing emerging technology in urban settings to evaluate urbanization's impact on environmental sustainability. Furthermore, policymakers can deploy the proposed framework in different locations based on their budget and requirements across urban areas.

5.3 Limitations

This study includes some limitations, which we will discuss in this section. First, we contacted individuals we believed were best suited to explore the study objectives, resulting in a limited number of participants who showed interest. Secondly, we conducted all the experiments in Malmö city for only four hours, limiting our ability to uncover enormous amounts of information. We only include limited environmental metrics for measurement because of the availability of sensors. Moreover, the toolkit can only send data when it connects to the laptop, which is the most significant limitation of this study. This study investigates how we can use technology to monitor the impact of urbanization on environmental sustainability and gives recommendations on what to consider during urban planning to make more sustainable cities. Ultimately, this study is similar to a helpful research report that suggests factors to consider during urban planning. Future studies in this area should draw motivation from this study's findings.

5.4 Future Directions:

This study provides interesting insights regarding urbanization issues and environmental sustainability. It also proposed a design framework to evaluate the impact of urbanization. Moreover, future research can follow the proposed framework as a guideline to create more efficient tools. In this study, the authors only conducted six interviews, which was limited. Therefore, future research should focus on conducting more interviews with experts to gain more insights about this pressing issue of urbanization and generalize the findings of this study in different contexts.

Furthermore, we believe that future research should also focus on conducting more experiments for longer durations. Experiments with more environmental metrics in different cities, utilizing more advanced sensors in their toolkit to compare values to improve data accuracy and reliability, help create more sustainable cities.

In addition, future research should replace the temperature sensor with Adafruit BME280 to get more accurate values. Future research can enhance the reliability of the whole toolkit by using an Arduino MKR Wi-Fi 1010 module with a connection to other platforms. The MKR Wi-Fi 1010 module is an excellent option for anybody looking to begin using the Internet of Things (IoT), regardless of experience level. For further security, it has the and the ECC508 crypto-chip. The board is a member of the MKR family, with a wide range of shields available for quick, easy project construction right out of the box. The MKR Wi-Fi 1010 enables the use of Bluetooth in projects and is compatible with the Arduino Cloud platform, Arduino IDE, and Arduino CLI. Moreover, it incorporates a lower-power Arm Cortex M0 32-bit SAMD21 processor. Future research also focuses on adding artificial intelligence algorithms to make accurate predictions and forecast the results of urbanization's impact on environmental sustainability in their toolkit.

6 Conclusion

This study aims to evaluate urbanization's impact on environmental sustainability using IoT-based tools. Thus, the researchers proposed two research questions to investigate the research objectives. The first question aims to investigate how urbanization impacts different environmental metrics that can compromise the sustainability of the environment. The second research question, designed to investigate the different environmental metrics affected by urbanization, supported the first research question. This was accomplished using the developed IoT tool for this experimental study. The study includes a qualitative research methodology followed by three critical stages: a literature review, an experiment, and interviews to answer the formulated research questions.

Moreover, we prepared an interview guide to analyze the effects of urbanization and the importance of technology in overcoming those issues. Six semi-structured interviews were conducted with individuals to discuss their strategies to overcome environmental problems using emerging technology. In addition, four experiments were conducted in Malmö City to investigate and measure different indicators using the developed IoT toolkit designed for this study. Based on this study's findings and in-depth analysis, we may conclude that urbanization increases resource demand, creating pressure on sustainability. However, in this experimental study, no impact of urbanization on measured metrics was found in Malmö City.

Furthermore, most of the participants suggest that technology has the potential to reduce the impact of urbanization and enhance sustainability. In addition, in this study, we proposed an IoT-based system to provide real-time data for urban planners, policymakers, and other government authorities to utilize the technology to evaluate the impact of urbanization. This study provides interesting insights regarding urbanization issues and environmental sustainability. It also proposed a design framework to evaluate urbanization impacts. However, on the other hand, there might be some implementation challenges, such as technical constraints, deployment expenses, security and privacy, expansion, seamless integration, and compliance with regulations.

Therefore, future research can follow the proposed framework as a guideline to create a more efficient tool using strong encryption and communication methods. Future research should utilize more advanced sensors to measure other environmental metrics such as SO₂, NO₂, and dust in their toolkit. Conduct more experiments in different regions to see the comparison in values. Replace the temperature sensor with Adafruit BME280 to get more accurate values. Future research can enhance the reliability of the whole toolkit by using an Arduino MKR Wi-Fi 1010 module with a connection to other platforms and adding artificial intelligence algorithms to make accurate predictions and forecast the results of urbanization's impact on environmental sustainability in their toolkit.

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Appendix

Appendix I: Interview Invitation

Dear [Name of the Interviewee],

We are a final year master's student in Innovation for Change in a Digital Society. Currently, we are researching "Evaluating the Impact of Urbanization on Environmental Sustainability through IoT-Based Tool" for our master thesis at Malmö University. With this letter, we invite you for a virtual interview. Your comprehension would be an excellent source for finding unique answers to our research. Below, you can find a brief introduction to our research.

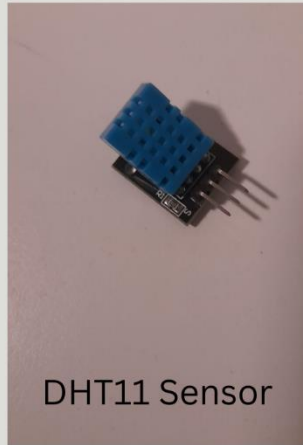
The main aim is to identify the impact of urbanization on environmental sustainability and how the practical integration of emerging technologies helps to reduce those effects of urbanization. Moreover, this project also aims to create a tool that can evaluate urbanization's impact by using IoT technology that helps city planners and policymakers plan urban design better to enhance the sustainability of the environment. Would you like to talk about this topic for approximately 40 minutes? As mentioned, the interview will be conducted online (via Zoom, Team, etc.) or in person. To protect your personal information, every interview participant will be assigned a unique ID so that the identity is not revealed during the interview analysis at a later stage. If you can not participate, please inform us in advance.

If you would like to participate, just inform us what day and time work best for you, and we will try our best to accommodate you. For questions and queries, please contact us at sulemanj970@gmail.com. We look forward to your reply.

Kind regards,

Suleman Junaid

Appendix II: Hardware Sensors



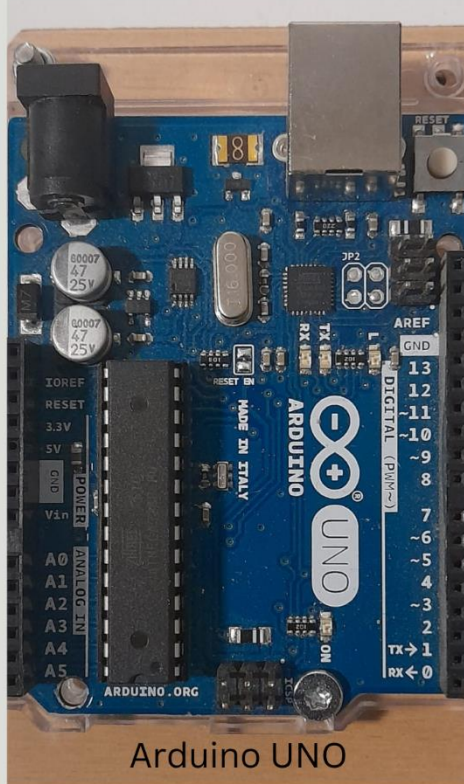
DHT11 Sensor



Adafruit SGP30
Sensor



Adafruit
SSD1351 OLED



Arduino UNO



MQ 135 Sensor

Appendix III: Informed Consent

The purpose of this study:

In this research, our objective is to investigate urbanization's impact on environmental sustainability and develop an IoT-based tool that can help different government officials better plan urban strategies and enhance environmental sustainability.

- To examine the function of digital tools in enhancing sustainability.
- To develop an IoT-based digital tool for evaluating urbanization's impact on environmental sustainability.
- To highlight the importance of digital tools and innovations in urban sustainability.
- To propose strategic recommendations for integrating emerging technologies in urban environmental sustainability.

Methods:

- Semi-structured interviews
- Experiment with developed IoT-based Tool

Consent Agreement

- I..... warmly agree to take part in this research study.
- I know that I can quit at any stage of the research.
- I know that I can withdraw my approval to utilize data from my interview, and in this case, all of my data will be deleted.
- I understand the aim and purpose of the study. I also have the chance to ask questions.
- I will not gain any advantage by participating in this research.
- I am permitted to record my interview, and researchers will keep it confidential until they complete their work.
- I understand that all of my responses will be kept confidential.
- I understand that all of my information will not be revealed in any report or document, which will be done by replacing my name, ID, etc.
- I can contact researchers at any time to get more clarification.

We trust that the interviewee has provided consent to take part in the research.

Signature of participant

Date

Signature of researcher
(Ramith and Suleman)

Date

Appendix IV: Codebook

Group 1: Urbanization	
Group 1.1: Definition	
Definition	The increasing number of people living in cities and surrounding areas is known as urbanization.
Coding Criteria	Any disagreement or variation in comments on urbanization is coded.
Example	"When we mention urbanization, we simply mean people moving from rural areas to urban areas in search of better opportunities and a better quality of life."

Group 2: Environmental Sustainability	
Group 2.1: Definition	
Definition	Management of environmental initiatives and laws that can minimize the consequences of climate change and maximize resource usage.
Coding Criteria	Statements that convey the notion of sustainability for the environment are coded.
Example	"In my opinion or knowledge, when we discuss environmental sustainability, it has to do with the efficient use of resources. It argues in favor of protecting the environment for future generations and preserving environmental norms to satisfy human needs".

Group 3: Experience	
Definition	The extent or kind of prior experience an individual has with environmental sustainability and urban development regulations.

Coding Criteria	Responses that pertain to an individual's prior exposure to urban development restrictions, environmental sustainability, and urbanization are coded.
Example	"I am an environmental strategist in Sweden. I have worked in the environmental department for many years. I work in a municipal office and am aware of the issues related to urbanization. I work in Malmö as a strategic planner, focusing on constructing parks and green spaces in residential areas to promote sustainability in urban centers".

Group 4: Urbanization Impact	
Group 4.1: Definition	
Definition	Urbanization has an enormous impact on infrastructure, including sustainability, accommodation, transportation, increasing energy consumption, increased CO2 emissions, increased UHI, and the use of fossil fuels.
Coding Criteria	Statements on how urbanization affects environmental sustainability are coded.
Example	"I do know that Land degradation occurs due to rapid urbanization, and as a result, there is less land for farming. Moreover, many environmental problems occur, such as air pollution and poor water quality in urban centers. Produces more emissions and increases urban heat".
Group 4.2: Water Quality and Management	
Definition	Water quality and management refers to how we can ensure that everyone can have access to pure drinking water and how we can manage and ensure its supply in various departments for other uses.
Coding Criteria	Statements that address the management of water quality in urban areas are coded.

Example	“How we can take all the wastewater from different sectors and clean it, store it for reuse purpose. Malmö municipality is making a big tunnel in Malmö to clean wastewater and store it for reuse”.
Group 4.3: Green Infrastructure and UHI	
Definition	The term "green infrastructure" describes having access to green public places, particularly in metropolitan areas, which can lessen the effects of urbanization and foster a more environmentally friendly atmosphere.
Coding Criteria	Coded statements highlighting the value of green infrastructure in urban areas to lessen the effects of urban heat and promote sustainability are included.
Example	"An initiative taken by Malmö where everyone can see at least three trees from their window and access parks within 300 meters from their residence".
Group 4.4: Land Degradation	
Definition	One definition of <i>land degradation</i> is the process of exploiting productive land due to multiple human uses.
Coding Criteria	Statements are coded to explain how urbanization impacts land degradation in urban centers.
Example	“There is a belief that because of urbanization, there is a decrease in arable land and consequent land degradation in urban centers. Construction of new homes also contributes to environmental degradation in urban areas”.
Group 4.5: Air Pollution	
Definition	The definition of <i>air pollution</i> is the discharge of numerous hazardous and toxic materials into the atmosphere due to human actions, including emissions from automobiles, different business sectors, and fossil fuels.
Coding Criteria	Statements that describe how different people perceive air quality, air pollution, industrial emissions, the use of fossil fuels, emissions from transportation, and

	other industries in metropolitan areas are coded.
Example	"Significant suburbanization is a factor in serious climate change issues, including higher CO2 emissions and fossil fuel consumption. Human activities, including burning fossil fuels, building, and transportation, cause most carbon emissions into the atmosphere".

Group 5: Adoption of Emerging Technologies and IoT	
Group 5.1: Definition	
Definition	The Internet of Things is a network in which many devices are connected to share data with the help of the Internet. Novel solutions are paramount if we want to develop a sustainable community. These developments can change the face of urban growth due to the rapid trend of urbanization, turning communities into long-term sustainability centers and a sense of environmental responsibility.
Coding Criteria	Coded statements highlight the significance of cutting-edge technologies, such as artificial intelligence, cloud computing, remote sensing, geographic information systems, and the Internet of Things, that may be applied to enhance urban areas and promote sustainability.
Example	"Malmö started an initiative to take temperature sensor data to give warnings and monitor elderly health, which costs almost 1.5M SEK. With this sensor data, they can determine what buildings are more vulnerable to higher temperatures."

Themes	Groups	Codes
Information about Urbanization	Urbanization knowledge and experience	What it is known as, what it represents, how it affects

Understanding Environmental Sustainability	Environmental Sustainability definition	Definition, consciousness, rules, and social influence
Impact of Urbanization	Urbanization Impacts (water quality and management, green infrastructure and UHI, land degradation, Air pollution)	Increased temperature, use of fossil fuels, CO2 emissions, land selection, handling of hazardous materials, policies
Technology Adaptation and Climate Change	The importance of technology and safety precautions	Enhancing policies, designing, developing technology, and ensuring correctness and dependability, IoT